University of Alberta

Relationships between *Sphagnum* Morphology and Absorbency of Commercial *Sphagnum* Board

by

Jean Ellen Malcolm ©

A thesis submitted to the Faculty of Graduate Studies and Research in
Partial Fulfillment of the requirements for the degree of Master of Science

Department of Botany

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Relationships between *Sphagnum* Morphology and Absorbency of Commercial *Sphagnum* Board submitted by Jean E. Malcolm in partial fulfillment of the requirements for the degree of Master of Science

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Abstract

Morphological characteristics of 16 species of *Sphagnum* L. (*S. angustifolium* (Russ.) C. Jens., *S. cuspidatum* Hoffm., *S. fallax* (Klinggr.) Klinggr., *S. fuscum* (Schimp.) Klinggr., *S. girgensohnii* Russ., *S. imbricatum* Hornsch., *S. jensenii*, H. Lindb., *S. lindbergii* Schimp. *ex* Lindb., *S. magellanicum* Brid., *S. majus* H. Lindb., *S. papillosum* Lindb., *S. pulchrum* (Braithw.) Warnst., *S. riparium* Angstr., *S. rubellum* Wils., *S. squarrosum* Crome and *S. wulfianum* Girg.) were compared to absorbency of *Sphagnum* board manufactured from those species using a detrended canonical correspondence analysis. The most absorbent board was made from *S. magellanicum*, and the least absorbent from *S. wulfianum*. The optimal leaf characteristics to maximize absorbency are 1) A large leaf curvature, up to a maximum of 300 micrometers to prevent breakage, 2) pores mostly on one side of the leaf to retain leaf integrity and 3) large pore diameter and a large pore area on one side of the leaf for efficient fluid uptake. Leaf length and width, cell size, cell length, and habitat of the species do not affect absorbency. Fibril frequency probably affects absorbency by preventing leaf breakage.

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List of Abbreviations

GATS	Gravimetric Absorbency Testing System
DP 30	Drying power measured after 30 minutes
DP 120	Drying power measured after 120 minutes
RC	Retention Capacity
LL	Leaf length
LW	Leaf width
LC	Leaf curvature
CL	Hyaline cell length
CW	Hyaline cell width
PD	Pore diameter
PF	Pore frequency
PA	Pore area
CC	Concave
CV	Convex
a	mean of all parts of leaf
b	basal part of leaf
c	centre of leaf
t	tip of leaf
e	edge of leaf
FF	Fibril frequency
dry wt	Dry weight of board
CANOCO	Canonical community ordination
DCCA	Detrended canonical correspondence analysis

Chapter 1: Introduction

1.1 Economic and Historical Importance of *Sphagnum*

For centuries, the genus *Sphagnum* L. has been known for its water absorbing abilities (e.g., Mackinnon, et al., 1992; Crum, 1988). These properties are largely due to the large fibrillose and porose hyaline cells in the *Sphagnum* leaf. *Sphagnum* is an important component of many peatlands. Peatlands are important in the hydrology of the landscape, (e.g., Crum, 1988) and the peat itself has economic importance (e.g., Crum, 1988). At present, the most important commercial uses of *Sphagnum* peat are in the horticulture industry (in potting soil mixtures and as a soil amendment) and in the manufacture of absorbent products.

Sphagnum is able to grow in ombrotrophic conditions (nutrients received solely from the atmosphere) because it is very efficient at sequestering nutrients. Uronic acids, acidic amino acids, and phenolic acids are present in cell walls, and are responsible for cation exchange (Richter and Dainty, 1989). Hydrogen ions are loosely attached, and are easily replaced by other cations (e.g., Ca^{++}, Na^{++}, Mg^{++}, K^{+}). Hydrogen ions are released, acidifying the surrounding water. The cation-exchange capacity of *Sphagnum* can be used in water treatment to remove heavy metals and other pollutants (e.g., Webster, et al., 1987).

Sphagnum has been used by Europeans and Aboriginal people in North America as a diaper absorbent, for sanitary napkins, as bedding and for treating wounds (MacKinnon, et al., 1992). More recently, *Sphagnum* was collected for use in bandages in World War I, since it was cheaper and more absorbent than cotton. Cotton was freed up for use as wadding in gun cartridge manufacture (Nichols, 1918). *Sphagnum* has antibiotic properties making it a better dressing than cotton (Crum, 1988).

Sphagnum is undeniably the most commercially important moss genus in the world. It has long been an important source of fuel for heating in some parts of the world, especially the British Isles. It is still an important component in the manufacture of Scotch whiskey. The malt used in whiskey manufacture is dried over slow burning peat fires, which gives Scotch its distinctive smoky flavour (Crum, 1988). In Canada, it is harvested for horticultural use and the manufacture of absorbent products for applications such as oil spill clean-up and sanitary napkins. Absorbent products containing *Sphagnum* are distributed worldwide and research is ongoing to expand commercial applications for *Sphagnum*.

1.2 Increasing Efficiency of Absorptive Product Production

Johnson & Johnson Research Canada has developed an absorptive product using *Sphagnum*. This product, called Absorbec, is used mainly in the manufacture of Prima ™ sanitary napkins. If fresh *Sphagnum* were used in board manufacture leaves would be virtually undamaged by decomposition and quality control would be improved, since the problem of heterogeneity of peat deposits would be eliminated (Yvon Levesque, pers. com.). Species of *Sphagnum* differ in the rate of decay of the macrostructure of the leaves. Hummock species generally decompose more slowly than hollow species (Johnson, et al., 1990). Once the macrostructure of the leaves has disintegrated, the peat is no longer useful for absorbent products (Yvon Levesque, pers. com.). The main objective of this study is to determine the species with the best absorbency, and the relationships between morphology and absorbency.

1.3 General Morphology of *Sphagnum*

Sphagnum is readily differentiated from other mosses by its habit and ultrastructural properties (figure 1.3.1). Stems are of indeterminate apical growth. Determinate branches are produced in fascicles of 3 to seven branches. At the apex of the stem, stem elongation does not occur and the branches are crowded into a capitulum. If the apex is killed (e.g. due to desiccation), buds from below the apex can develop to allow for continued growth. New shoots can arise from peat that is more than 25 years old (Clymo and Duckett, 1985).

Stems

The stems consist of three layers: an inner core of parenchyma, surrounded by scleroderm of thick-walled prosenchyma, surrounded by hyaloderm (Crum, 1984). The hyaloderm is one or more layers

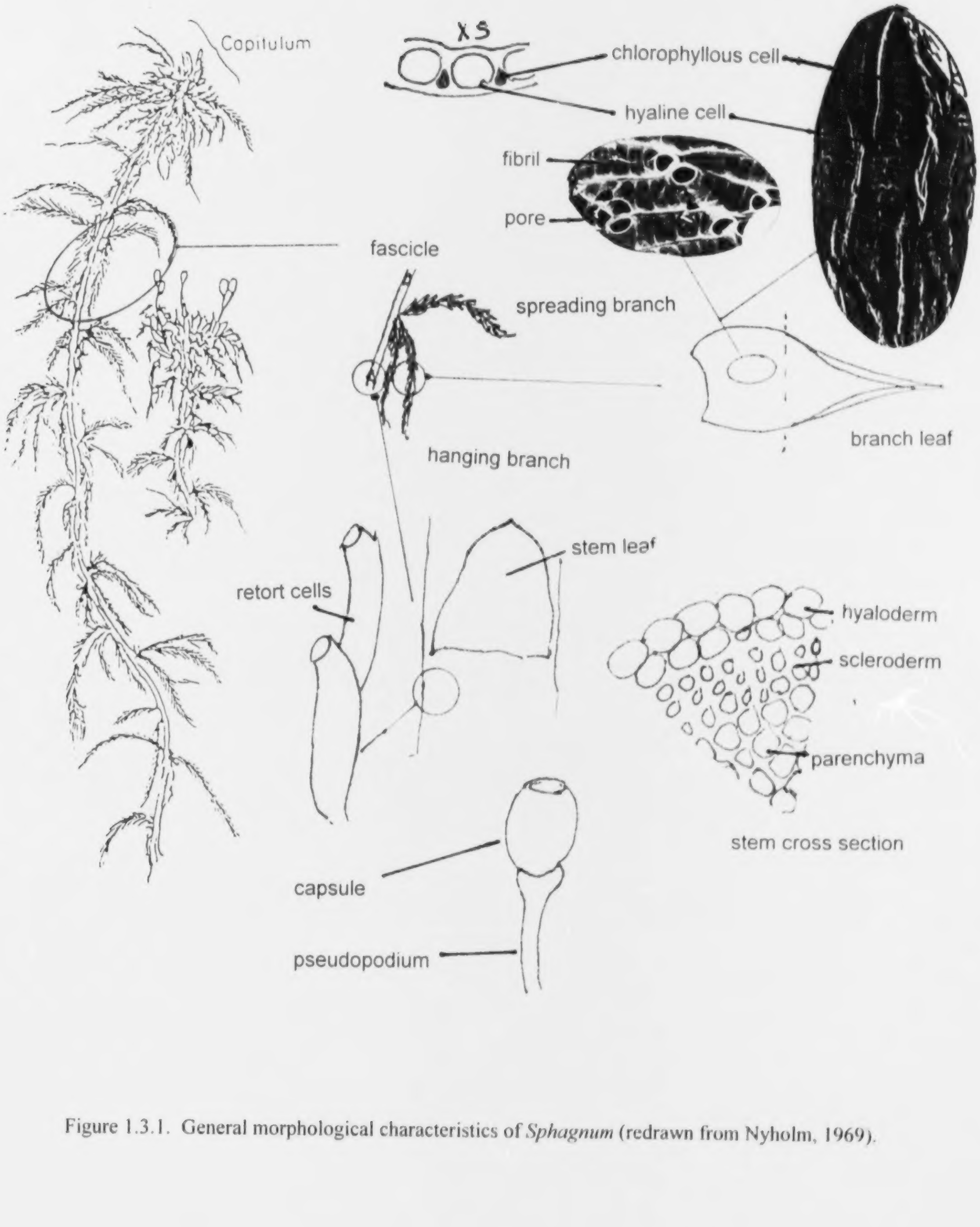

Copitulum
XS
chlorophyllous cell
hyaline cell
fibril
pore
fascicle
spreading branch
hanging branch
branch leaf
stem leaf
retort cells
hyaloderm
scleroderm
parenchyma
stem cross section
capsule
pseudopodium

Figure 1.3.1. General morphological characteristics of *Sphagnum* (redrawn from Nyholm, 1969).

of hyaline cells. These cells may be fibrillose and porose. Stem morphology was not included in this study, because stems are removed during board manufacture (except in whole plant treatments).

The thickness and strength of the stem vary among species. In *S. wulfianum* H. Lindb, the stem is sclerified, as individual capitula are supported by the stem rather than by surrounding plants. In hummock species, such as *S. fuscum* (Schimp.) Klinggr., the stems are fine, and will not support the weight of the plant; plants are held upright by surrounding plants, often in dense populations. In submerged species, water movement up the stem is not important, but stems must be strong enough to hold the capitulum in a position of favourable light capture.

Branches

Spirally arranged around the stem are fascicles (groups of branches originating from one location on the stem) containing two types of branches, spreading and pendant. These branches are (normally) determinate in growth. The hyaloderm of the branches usually consists of one layer of hyaline cells, which may be fibrillose and porose. In some species, retort cells (enlarged hyaline cells with a pore terminating a short neck) are present in the cortex. Usually the spreading and hanging branches have slightly different morphology, with the spreading branches more robust, and the hanging branches more slender. At the apex, the stem does not elongate, but the branches do, and are crowded together to form the capitulum. Below the apex, the cells in the stem elongate, and the fascicles of branches (3 to 7) are separated.

Leaves

Sphagnum has two types of leaves: stem leaves and branch leaves. There is a difference in morphology between stem and branch leaves. Stem leaves are taxonomically important, especially in field identification (Lange, 1982). However, branch leaves are far more numerous than stem leaves (stem leaves account for less than one percent of leaves on a plant). Stem leaves probably remain attached to the stem during processing, and are not present in *Sphagnum* board (except in whole plant treatments). Leaves can be blunt or acute. In species of section Sphagnum, leaves are cucullate (tip forms a hood) (Crum, 1984).

Leaf length may be affected by habitat. In *Sphagnum strictum* Sullivant leaves from drier habitats were shorter and had narrower tips than leaves from wetter habitats (Sastad and Flatberg, 1993).

At maturity, leaves are composed of hyaline and chlorophyllous cells (Moldenhawer, 1812). The hyaline cells are usually strengthened by annular or spiral thickenings (called fibrils) and are porose. Ornamentations of the inner hyaline cell wall (where the hyaline cell adjoins to the chlorophyllous cell), such as papillae or ridges, occur in some species.

Leaf Development

Summary

A leaf originates from one cell with two cutting faces that undergo about 10 divisions, and was first described by Nageli (1845). These form closely packed diamond-shaped cells in one layer. These cells undergo another division. Of the resulting daughter cells, one does not divide and differentiates into the hyaline cell, while the other divides and differentiates into two long, thin, chlorophyllous cells; this results in the 1:2 pattern of hyaline to chlorophyllous cells.

Pattern of cell division

A model of the pattern of cell division in a young leaf primordium was developed by Holcombe (1984) and is illustrated in figure 1.3.2. The leaf develops through divisions of an apical cell. The apical cell has two cutting faces, and with each successive division, alternates the plane of the division. The first derivative of a division of the apical cell divides, forming a three celled "merophyte" (the packet of cells produced by segmentation of apical cell derivatives). Mitosis always occurs in a plane perpendicular to the longest wall of the cell. Mitosis occurs not only in the apical cell, but in all of the merophytes. Divisions occur in the middle of the leaf after other divisions have ceased. Divisions in the middle of the leaf are responsible for leaf curvature and the cucullate tip characteristic of leaves of species in Section *Sphagnum*.

After divisions have ceased, all of the cells in the branch leaf are chlorophyllous, about the same size, and are reminiscent of the cells of other mosses. At this point, all the leaf cells contain abundant plasmodesmata (Schnepf and Sych, 1983). Each cell divides longitudinally. One of those cells divides perpendicular to the previous division. The result is a triad of "mother cells". The two smaller cells will

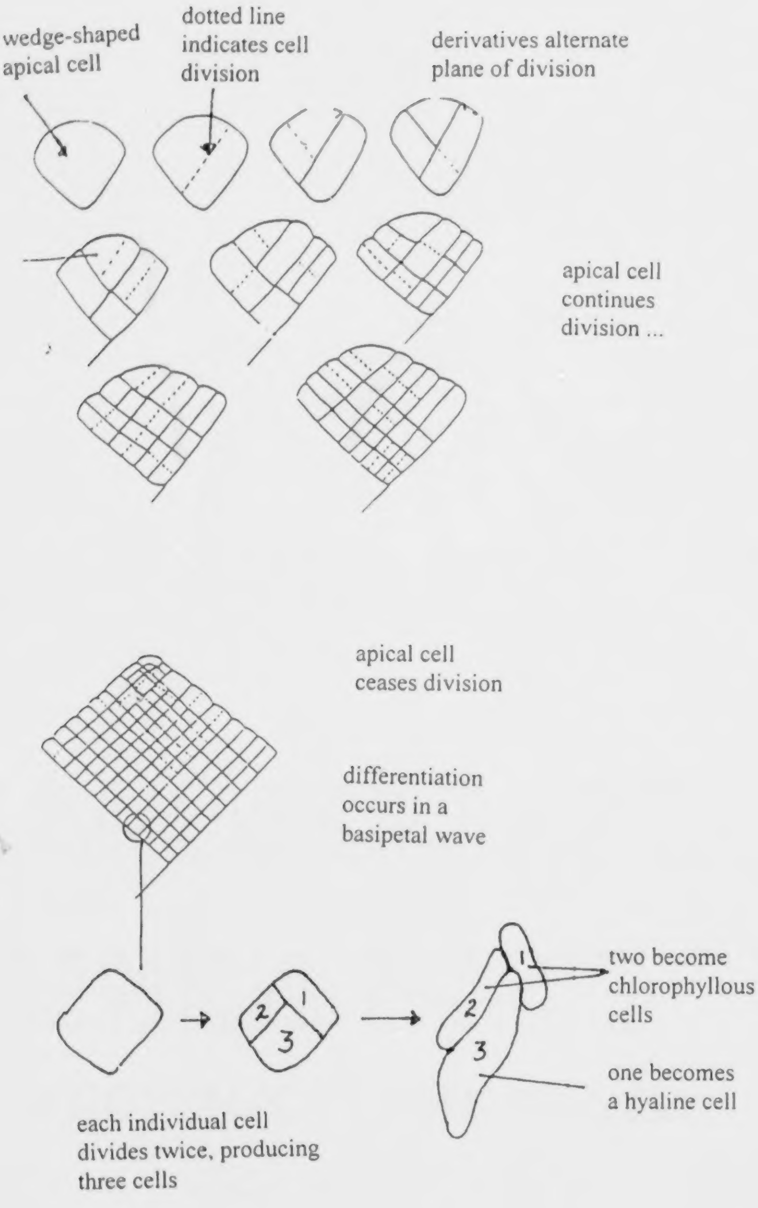

wedge-shaped apical cell
dotted line indicates cell division
derivatives alternate plane of division
apical cell continues division ...
apical cell ceases division
differentiation occurs in a basipetal wave
2
1
3
two become chlorophyllous cells
one becomes a hyaline cell
each individual cell divides twice, producing three cells

Figure 1.3.2: Patterns of development in *Sphagnum* (redrawn from Holcombe, 1984).

differentiate into the chlorophyllous cells, and the larger one will become the hyaline cell. These divisions occur in a wave beginning at the tip of the leaf, and proceeding to the base of the leaf (Holcombe, 1984).

Differentiation

Differentiation into the two cell types occurs in a basipetal fashion. A "wave" of differentiation occurs, beginning at the apex, progressing downward in a band of differentiation (Holcombe, 1984). There is a sharp difference between the cells on either side of this band (Holcombe, 1984). The differentiation process in the hyaline cells involves the formation of annular or spiral thickenings (fibrils) composed of cell wall material, and of large pores in the cell wall.

Expansion of the pro-hyaline cell occurs through the enlargement of a single vacuole in the middle of the cell. As the vacuole enlarges, the cell wall stretches to accommodate the increase in volume. This vacuole probably contains hydrolytic enzymes, which were detected by Holcombe (1984) study, but not localized. The cytoplasm at this stage is present in a thin layer around the vacuole and appears to be active. It is probably involved in fibril and pore formation.

After the cell has completely elongated, the fibrils are formed. Strands of cytoplasm are seen radiating from the nucleus, and these may be involved in the positioning of the fibrils, but the mechanism is as yet unclear. Wall material is laid down in the cells, but is preferentially laid down in the position of the fibrils (Holcombe, 1984). Fibrils are simply thick areas of wall deposition, extending into the lumen of the cell. In some species, there are wall deposits forming papillae and ridges that are laid after fibril formation (Anderson and Ammann, 1991).

The pores are the result of the lack of wall deposition in certain areas. Holcombe (1984) suggests that they may be formed by a large organelle, appressed to the cell wall, preventing deposition in that area. This would leave a circular area consisting of thin primary wall. When autolysis occurs (release of the lytic enzymes of the vacuole) this thin wall is eroded away. The pore membrane that remains may also be mechanically eroded after cell death and desiccation.

In some species of *Sphagnum*, "resorption" occurs; and is the loss of parts of cell walls on leaf edges, resulting in, among other features, the "resorption furrow" (discussed in Holcombe, 1984). The mechanism for this is unknown, but it is possible that the autolytic enzymes involved in the death of the cytoplasm, and possibly in the digestion of the pore membrane, may be involved (Holcombe, 1984).

Function Of Leaf Morphological Characteristics

The large hyaline cells of *Sphagnum* probably serve as temporary water storage vessels benefiting the neighbouring chlorophyllous cells (Holcombe, 1984). Water stored in the hyaline cells, and between leaves in branches would serve to maintain the humidity within a hummock at a high level, and desiccation within living cells is avoided. In the surface 2.9 cm of *S. fuscum* hummocks, 27% of the water volume is located in the hyaline cells, and 71.8% in the spaces in-between leaves, branches and stems (Romanov, 1968).

The function of fibrils is to strengthen the individual hyaline cells. This is especially important during desiccation. In many species, the leaves change shape when dry (e.g. *Sphagnum squarrosum* Crome branch leaves become more reflexed). Shape changes may be a mechanism to optimize water capture efficiency when dry, and water retention efficiency when wet.

Pores provide a rapid means of entry into the hyaline cell as it becomes available. Water in the hyaline cell is trapped by capillary forces at a potential of about -30 kPa (able to support a water column of 3 m) (Clymo and Hayward, 1982). This water is then available to the chlorophyllous cells. An empty hyaline cell has a strong capillary pull. Pores are probably involved in the wicking action along a *Sphagnum* branch. This was first recognized by Moldenhawer (1812).

Pores may also be an adaptation to avoid damage to the live cells during desiccation (Lewis, 1988) by another mechanism. As the hyaline cells dehydrate, a bubble of air is pulled in through the largest pore in the cell. The lumen of the cell then fills with air, forcing water to flow into the surrounding tissues (which are the green chlorophyllous cells). This movement of air bubbles into the dead cells results in embolism of the dead cells and is termed "airseeding".

Water movement between living cells in *Sphagnum* occurs through plasmodesmata, just as in other plant groups. These plasmodesmata occur frequently in young parenchymatous tissue (Baker, 1988). As the cells mature and deposit wall material, many of these perforations are protected from secondary wall deposition. This leaves small circular and elliptical areas, that form pits occurring opposite each other in adjacent cells. These pits contain fields of plasmodesmata 20-35 nm in diameter.

Since these pits are so frequent and so widespread, and are found in even the highly thickened cells of the stem, communication between cells is possible. It is possible that communication between cells may be similar to that of vascular plants using plant hormones. Evidence that this may be true is that *Sphagnum* appears to show possible apical dominance (Clymo and Duckett, 1985), similar to vascular plants. New shoots grew from peat cores harvested from up to 30 cm below the surface, but peat discs from the surface (containing the apices of the plants) did not produce these same innovations. Rydin and Clymo (1989) showed, using 32P and 14C that carbon and phosphorous move towards the apex in a *Sphagnum* plant, even when mass flow is moving downwards. This indicates that *Sphagnum* has a mechanism for moving solutes within the plant, presumably through the plasmodesmata.

1.4 Habitat

General Classification

In Canada, *Sphagnum* is often found in fens or bogs, classified on the basis of mineral availability. Some species are found on the forest floor in wet depressions. Fens are minerotrophic (mineral nutrients supplied by geogenous (in contact with mineral substrate) water); bogs are ombrotrophic (mineral nutrients supplied from precipitation and the atmosphere). Two types of bogs are raised bogs and blanket bogs the latter forming over undulating ground in humid areas. Fens can be classified as "mineral rich" or "mineral poor". Bogs and fens can also be classified on the basis of acidity and alkalinity. Bogs and poor fens are acidic and *Sphagnum*-dominated, and rich fens are alkaline and brown-moss dominated. These, and other habitats of *Sphagnum* are discussed in Crum (1988).

Habitat types

Sphagnum may be found submerged in pools, in hollows, on hummocks, in lawns, in carpets or on the forest floor (e.g., Crum, 1988). Hummocks and hollows often alternate in a peatland complex. Hummocks are cushions of *Sphagnum* of varying density. Often, vascular plant species (e.g., *Vaccinium oxycoccus* L. , *Smilacena trifoliata* (L.) Desf., *Ledum groenlandicum* Oeder, and many others) (Crum,

1988) and bryophyte species (e.g., *Polytrichum strictum* Brid. (in Vitt et al., 1988)) are also found on the surface of the hummock. Individual *Sphagnum* plants within the hummock do not require a strong stem for support. Instead, the stem may be differentiated for water transport, with support provided by neighbouring plants.

The surface of the hummock is a single layer of capitula, often tightly packed. The interior of the hummock maintains high humidity. The compactness of the hummock, in addition to morphological features of the plant, enable wicking to occur over large distances (for example, the distance to the water table was greater than 50 cm for *S. magellanicum* collected at Clear Lake).

The senescent part of the plants (often that part of the plant more than one or two centimeters below the capitulum) in hummock species decompose very slowly. The rate of decomposition of leaf macrostructure varies between species, and is more rapid in species that occupy hollows than those in hummocks (Johnson, et al., 1990). In hummocks, the morphological characteristics of the leaves responsible for wicking (the source of the water supply) is maintained by slow decomposition, and in hollow species rapid decomposition prevents the capitula from being far removed from the water table. Once macrostructure of the leaves collapses, the wicking ability of the peat is greatly reduced (Johnson, et al., 1990).

The *Sphagnum* collected for use in monospecific board was a mixture of living material collected from the surface, and of senescent material from below the surface. The senescent material collected had not undergone decay of the structure of the plant. However, some decomposition had likely occurred, but the extent of this was not determined. Szumigalski and Bayley (1996) found that air-dried *Sphagnum fuscum*, when placed under the surface of a peat bog, loses 14% of its dry weight after one year, but only an additional 4% in the second year. It was not determined what percentage of the weight loss was the soluble fraction, and what percentage of weight loss was due to decomposition of cell wall material. For absorbent products, the cell wall material is more important than the soluble fraction of the plant.

Hollow species generally have a much looser growth habit than hummock species. They usually occur only a few centimeters from the water table, or at the water table. Studies have been done on the desiccation tolerance of hummock and hollow species. It has been found that hollow species are more tolerant to desiccation than hummock species (Wagner and Titus, 1984). This may be because desiccation does not occur often in hummock species as compared to hollow species because of the efficiency of hummock species at wicking water from the water table. However, the relative occurrence of desiccation events in hummock and hollow species in the field has not been determined.

In submerged species, water is readily available, but carbon dioxide is a limiting factor. Many species form floating mats of vegetation forming large expanses (carpets). The growing apex in located just above the water table. In mat species neither water availability (floating mats move with the water table) nor gas exchange is a limiting factor. Nitrogen diffuses from water beneath the peat layer to the growing portion of the mat (Haraguchi and Matsui, 1990), and flooding of the mat was important for the nutrient supply to the surface.

1.5 Summary of Objectives

It has long been postulated that the hyaline cells of *Sphagnum* are responsible for the unique absorptive and wicking properties of *Sphagnum* (Moldenhawer, 1812). Some species of *Sphagnum* can absorb more than 20 times their dry weight in water (Vitt, et al., 1975). *Sphagnum* is a large genus (up to 300 species), with 10 infrageneric sections. At least 52 and perhaps up to 83 species occur in North America (Crum, 1984; Andrus and McQueen, pers. com.), a few of which have several varieties.

The purpose of this study is to collect species of *Sphagnum* with diverse morphological features, and determine the species with the highest absorbency and the morphological characteristics that are associated with high absorbency using a multivariate approach. The morphological features of *Sphagnum* measured were those concerning the leaves, because stems are screened out during board production. Most of the measurements were features of the hyaline cells (cell size, pore size, pore area, pore frequency and fibril frequency), because the hyaline cells are likely responsible for absorptive properties. Associations between morphological characteristics and absorbency values were determined using a detrended canonical correspondence analysis (DCCA) within the CANOCO program.

Chapter 2: Material Collection

2.1 Introduction

To evaluate the effects of morphology on absorbency, it is necessary to examine species with a wide range of morphological features. Species from five subgeneric sections of *Sphagnum* were chosen on the basis of availability. Collections were made in Quebec, Alberta and British Columbia.

In commercial *Sphagnum* board production, the mined peat used has undergone some degree of decomposition. Decomposition is both the chemical and physical breakdown of organic material. The *Sphagnum* leaves present in commercial board are mostly intact, but it the degree of chemical decomposition that has occurred is unknown. This chemical decomposition may affect breakage of the leaves which will in turn affect absorbency characteristics. In the monospecific samples, material that has not undergone decomposition visible to the naked eye was collected. However, some decomposition had probably occurred in the senescent parts of the plants collected. After one year below the surface of a bog, air-dried *Sphagnum* loses 14% of its weight, and 4% of its weight in the second year (Szumigalski and Bayley, 1996). However, it is unknown how much decomposition occurs in senescent plant parts which are still attached to growing apices. Clymo and Duckett (1985) determined that these senescent plant parts still contain living cells, and are able to regenerate new plants.

2.2 Collection Methods

Once a monospecific mat of a species (table 2.2.1) was located and identified, a sample 10 to 25 litres was collected. The moss was collected by hand to avoid including other *Sphagnum* species. The thickness of the layer collected depended on the species. Only plant material where leaves and branches were still attached to the stem, and no decomposition other than loss of chlorophyllous cell contents was noted, was collected. There was no breakdown of macrostructure of the leaves in the samples collected. Samples were transported to Montreal for processing into board. Samples of each species from this study are in University of Alberta Herbarium (ALTA).

Table 2.2.1: Species collected and processed into *Sphagnum* board.

Section *Sphagnum* L.	
Sphagnum magellanicum Brid.	Clear Lake, Alberta
Sphagnum imbricatum Hornsch. *ex* Russ.	1 km east of Prince Rupert, British Columbia
Sphagnum papillosum Lindb.	Péribonka Peatland, Quebec
Section *Acutifolia* Wils.	
Sphagnum fuscum (Schimp.) Klinggr.	Ste. Marguerite Peatland, Quebec
Sphagnum girgensohnii Russ.	Tipping Rock, British Columbia
Sphagnum rubellum Wils.	Péribonka Peatland, Quebec
Section *Cuspidata* (Lindb.) Schlieph. *ex* Schimp.	
Sphagnum angustifolium (Russ.) C. Jens.	Ste. Marguerite Peatland, Quebec
Sphagnum cuspidatum Hoffm.	L'Ascension Peatland, Quebec
Sphagnum fallax (Klinggr.) Klinggr.	Péribonka Peatland, Quebec
Sphagnum jensenii H. Lindb.	Goose Mountain Tower Road, Alberta
Sphagnum lindbergii Schimp. *ex* Lindb.	Goose Mountain Tower Road, Alberta
Sphagnum majus H. Lindb.	L'Ascension Peatland, Quebec
Sphagnum riparium Angstr.	Goose Mountain Tower Road, Alberta
Sphagnum pulchrum (Braithw.) Warnst.	Péribonka Peatland, Quebec
Section *Squarrosa* (Russ.) Schimp.	
Sphagnum squarrosum Crome	12 miles SW of Hines Creek, Alberta
Section *Polyclada* (C. Jens.) Warnst. *ex* Horell	
Sphagnum wulfianum Girg.	1 km N of Fox Creek, Alberta

2.3 Handsheet Board Manufacture

In handsheet board manufacture, the leaves are separated and mixed with kraft wood pulp (used in paper manufacture), 1.25 cm polyester fibers and surfactant, and the mixture is placed on a 30 cm X 30 cm forming board. An additional kraft layer is added to upper and lower surfaces. Water is removed by suction, and the handsheet is dried and calendered. For comparison, whole plants were used for some boards. The handsheets were produced by Johnson & Johnson Research Canada in Montreal.

Chapter 3: Absorbency Tests

3.1 Introduction

Standardized tests have been devised by Johnson & Johnson Research Canada, where *Sphagnum* board was first developed, to evaluate the absorbency of materials. The absorbency tests include Gravimetric Absorbency Testing System (GATS), drying power, impact, and retention capacity. Density, dry weight and hygroscopic water content of the board are also measured in order that comparisons between the *Sphagnum* boards can be made.

Several features are important in an absorbent product. For many applications, the maximum amount of liquid the product can hold is important. **Gravimetric Absorbency Testing System** (GATS) is used for this feature. Ideally, an absorbent material should leave a dry surface. The ability of a material to import liquid from one material to the absorbent material is the **drying power** of the material. To demonstrate the importance of these two characteristics the analogy of a towel can be used. The "ideal" towel holds a large amount of water, which does not drain out without force (a high GATS), and removes most of the water from the surface without leaving liquid behind, and with as little effort expended by the person operating the towel as possible (a low drying power). Free liquid poured onto the towel is completely absorbed without any runoff (a high **impact**).

The ability of the board to draw liquid away from a source is important for the application of sanitary napkins. The standardized test for this is drying power. Drying power is the amount of liquid the board can remove from a saturated wood pulp pad in a certain time period per gram of pad. The liquid used, Pr-SPTF-1, has a salt concentration and viscosity similar to menstrual blood, (25 times the viscosity of water) which is an important consideration when testing drying power for use in sanitary napkins.

3.2 Materials And Methods

3.2.1 Gravimetric Absorbency Testing System (GATS)

The Gravimetric Absorbency Testing System (GATS) was developed by Johnson & Johnson to measure the maximum amount of liquid the *Sphagnum* board can hold against the force of gravity. GATS is a measurement of the volume of the expanded board unoccupied by solid material - the pore space. The height of the water column in this test can be adjusted in order to measure the total amount of pore spaces of specific size ranges. The standard difference of water column level is one centimeter, which measures the total volume of pore spaces between 0 and 1480 micrometers, since this will encompass all pores in the board. The inverse nature of the height of the water column in a capillary tube and the width of the capillary tube is demonstrated in figure 3.2.1.1. As the pore size increases, the height of the water column decreases. Smaller pores will therefore have a greater "pull" with regards to liquid uptake.

At the standard water column difference of one centimeter, pores with a radius smaller than 1480 micrometers will be completely filled with water. Because the average calendered thickness of commercial *Sphagnum* board is only 780 micrometers, all pores will be filled with water at a column height of one centimeter. Capillary force will pull water into the board replacing the small amount of air that was present with water. Upon wetting the board will expand as the leaves regain their original shape, and pore space size will expand. As the board expands, water is taken up in much the same manner as an eyedropper fills with water when the bulb is released. Pore spaces larger than 1480 micrometers are unlikely to occur in *Sphagnum* board since the largest leaf width is only about 1000 micrometers. Even with a high curvature, a leaf of this size will not produce a "capillary tube" larger than its own width. In other absorbent products, such as a cellulose sponge, pores larger than 1480 micrometers

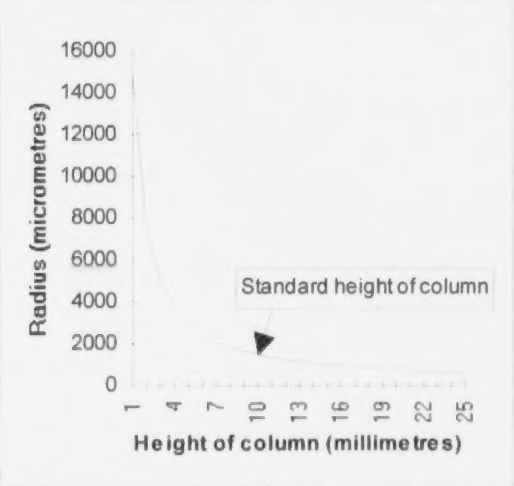


Figure 3.2.1.1: Relationship between column height of liquid in capillary tube and radius of capillary tube when distilled water is the liquid used. Arrow indicates the standard column height and maximum pore size in the GATS test (provided by Johnson & Johnson Research).

may occur. The force of gravity will cause those larger pores to drain, except for water which adheres to the walls of the pore space.

The Gravimetric Absorbency Testing System (GATS) is produced under license by M/K Systems Inc. (Danvers, MA 01923). The exact specifications of this test are shown in Appendix 1. GATS is measured by placing a piece of *Sphagnum* board of a known weight cut to a standard size and shape (usually round) on a porous glass filter. The board rests on the porous plate for 15 minutes, and water moves into the board (see Appendix 1). The amount of water entering the *Sphagnum* board is determined. This result is divided by the weight of the *Sphagnum* board corrected to 12% water content, in grams, to obtain GATS. Three replicates are performed for each sample board. The apparatus used and the computer generated output is shown (figure 3.2.1.2).

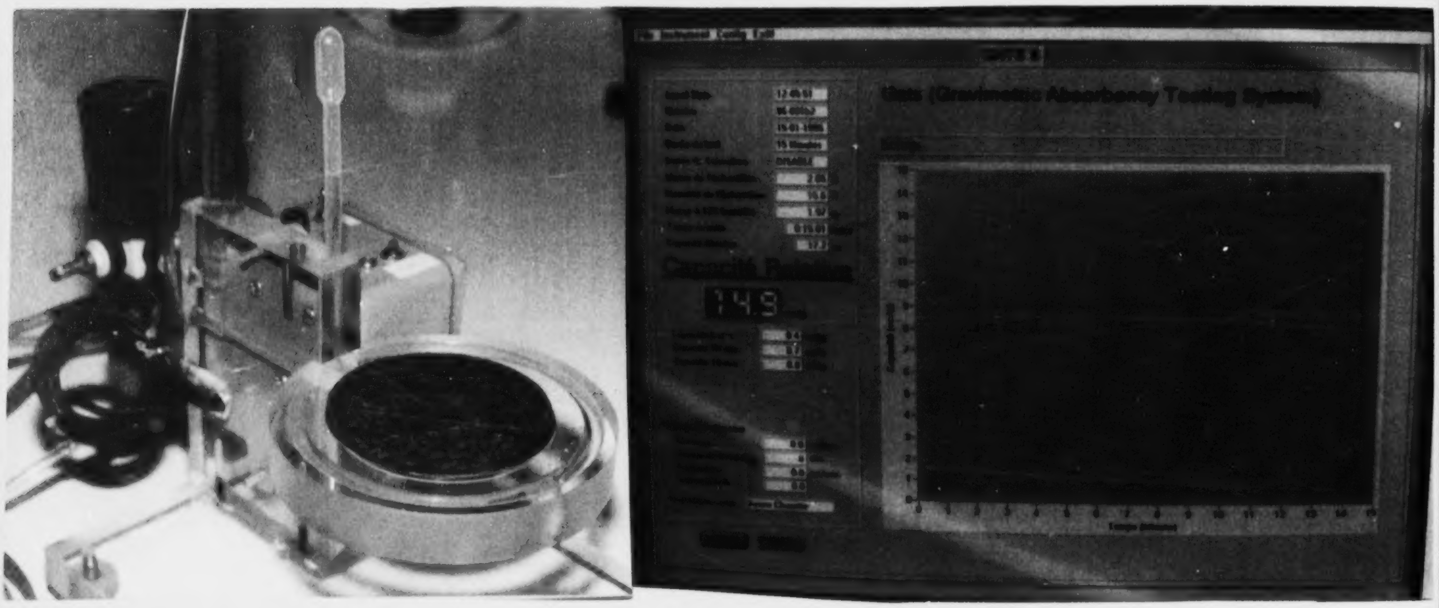


Figure 3.2.1.2: (A) GATS apparatus showing *Sphagnum* disc saturated with water. (B) Computer generated output for GATS test values. The GATS value is read after fifteen minutes.

3.2.2 Drying Power

Drying power is a measurement of the wicking power of the *Sphagnum* board. It is determined by measuring the amount of a test liquid the board is able to draw away by capillary migration from a wood pulp pad in a specific time period, represented in milliliters of liquid drawn away per gram of pad (corrected to 12% Water Content). Drying power represents the amount of liquid that is left in the wood pulp pad. A low value for drying power indicates the board is able to draw most of the liquid from the wood pulp pad; therefore the board has a strong ability to draw liquid away from a source.

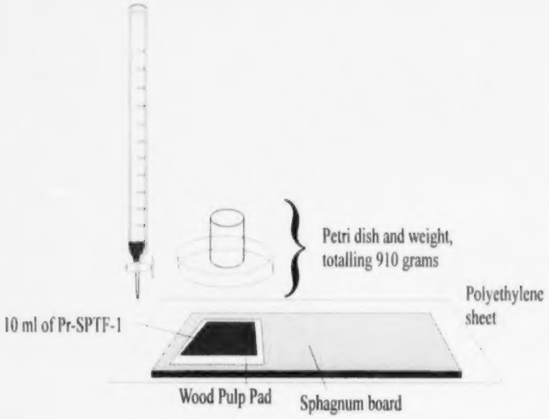


Figure 3.2.2.1. Set-up for drying power test. Drying Power is the amount of liquid removed from the pad per gram of weight of the pad.

A strip of *Sphagnum* board approximately 25 centimeters by 5 centimeters is placed on a countertop (figure 3.2.2.1). All boards are manufactured and conditioned to a hygroscopic water content within the range of about 12% to 16% water by weight. There is no free water in the board. Weight of board is corrected to the standard hygroscopic water content of 12%. A 5 X 5 centimeter wood pulp pad, sub-saturated with 10 ml Pr-SPTF-1, is placed at one end of the strip with a piece of polyethylene, a Petri dish and a weight together totaling 910 grams to ensure that evaporation is not a factor and all parts of the pad are in contact with the board. It is important that the wood pulp pad is not over-saturated, as the point of the test is to see how much liquid the *Sphagnum* board can draw away from being held by the pad. Pr-SPTF-1 is a liquid that has a salt concentration and viscosity similar to menstrual blood (approximately 25 times the viscosity of distilled water). The pad is weighed at the start of the test, at 30 minutes and at 120 minutes. Three replicates of each board are performed. The drying power test was developed by Yvon Levesque of Johnson & Johnson Research Canada.

3.2.3 Impact

Impact is a test used to determine the wetting ability of the *Sphagnum* board. It is the amount of a 1% NaCl solution the *Sphagnum* board retains on "impact". A rectangular piece of *Sphagnum* board is placed on a 45 degree angled platform (figure 3.2.3.1). The volume of the 1% NaCl solution used is that volume which has a mass equal to ten times the mass of the *Sphagnum* board. The 1% NaCl solution is released from a burette (1000 ml Pyrex™ glass burette) with the stopcock fully open onto the upper portion of the board. The amount of run-off that is collected at the bottom is measured with a graduated cylinder. The percentage of solution the board absorbs is the "impact". The impact test is replicated at least two times (three if sufficient material was available). Impact tests were designed by Yvon Levesque of Johnson & Johnson Research Canada.

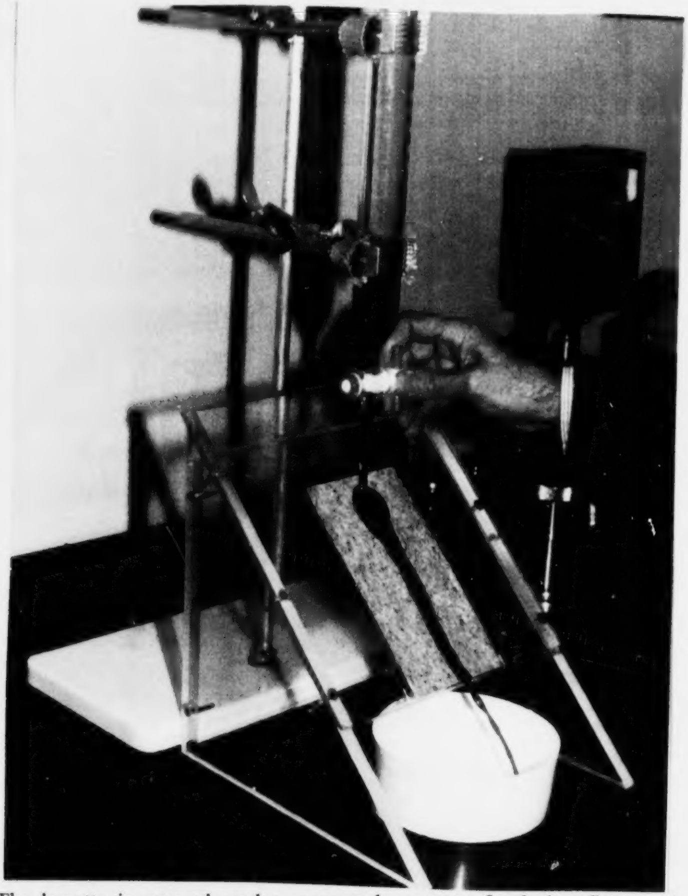


Figure 3.2.3.1: Impact test. The burette is opened, and a measured amount of solution flows onto the *Sphagnum* board. The amount of liquid that collects in the container is measured, and the amount that the board absorbed is determined.

3.2.4 Retention Capacity

Retention Capacity is a measurement of the amount of water a fresh moss sample can retain. A moss sample is chopped and mixed with water to form a slurry. This slurry is poured into a cylinder with a screen on the bottom (figure 3.2.4.1), and the excess water is drained off. The amount of water that remains in the sample is "Maximum Retention Capacity" (formula 3.2.4.1). "Retention Capacity - 300g" (RC 300g) is the equivalent measurement with a total mass of 300 grams placed on the peat sample. The volume of water that drains off is measured. "Retention Capacity - 1200g" (RC 1200g) uses a total of 1200 grams of mass, and the volume that drains off is again measured. The remaining moss plug is dried at 120 degrees Celsius and its water content is determined. This value is RC 1200g. Retention Capacity (1200g) plus the volume of water that drained off with 1200g of weight is RC 300g. Retention Capacity (300g) plus the amount that drained off with 300g of weight is Maximum retention capacity. Values are in milliliters of water per gram of dry weight of *Sphagnum*. Tests are done once. Retention capacity tests were designed by Yvon Levesque of Johnson and Johnson Research Canada.

Formula 3.2.4.1

$$\text{RC Max} = \frac{\text{RC 1200g + RC 300g + vol. H20 drained between 0 and 300g loading (ml)}}{\text{dry weight (g)}}$$

Where:

$$\text{RC 1200g} = \frac{\text{vol. H20 remaining after 1200g loading (ml)}}{\text{dry weight (g)}}$$

$$\text{RC 300g} = \frac{\text{volume H20 drained between 300g and 1200g loadings (ml)}}{\text{dry weight (g)}}$$

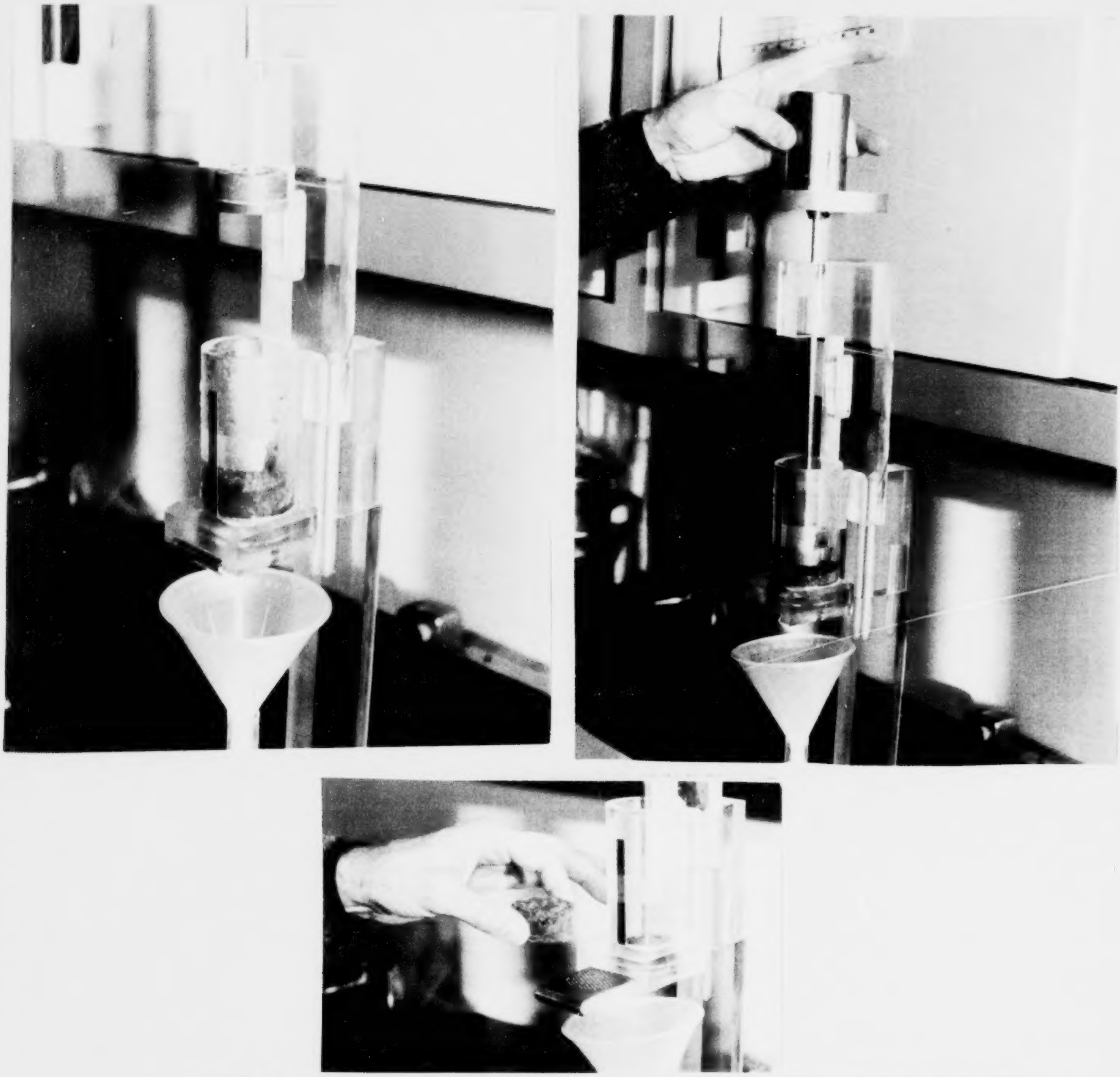


Figure 3.2.4.1. Apparatus for measuring Retention Capacity. (A) Maximum Retention Capacity. Slurry is poured into container, and water is drained and discarded. (B) Metal plate (300g total weight) is placed on top of *Sphagnum* sample and water drained is collected. An additional 900g weight is placed on top of metal plate and water drained is measured. (C) *Sphagnum* plug is removed from apparatus, and water remaining and dry weight are determined.

3.2.5 Density, Dry Weight and Percent Water Content

Density, dry weight and percent hygroscopic water content are measured characteristics of the individual boards. For instance, the percent water content must be within a certain range when drying power tests are done to ensure the tests are comparable to one another. Results for GATS and drying power are adjusted to reflect a water content of 12%. *Sphagnum* with a low water content has a tendency to become hydrophobic, but surfactants are added during board production to prevent this.

Density is the mass of one cubic centimeter of the *Sphagnum* board at 12% water content measured in $grams \cdot cm^{-3}$. Dry weight is the mass of one meter square of board ($g \cdot m^{-2}$). Percent water content is the amount of hygroscopic water present in the *Sphagnum* board by weight. Since the hygroscopic water content can change over time due to different relative humidity levels in the air, it is important that water content is calculated immediately preceding absorbency tests. It is also important that the board used in water content calculations has been stored in the same room as board used for GATS and Drying Power, as differing water contents can affect these results.

3.2.6 Analysis Of Results

Handsheets of seventeen samples were prepared at Johnson & Johnson Research, using the same proportions of *Sphagnum,* polyester thread, paper fibers and surfactants as in commercial board. Results from these handsheets were compared to results from a typical commercial board. Commercial averages, and commercial specifications were included where available to compare how the individual handsheets compare to actual commercial products.

Principal boards were prepared from monospecific samples of sixteen species (*Sphagnum imbricatum, S. magellanicum, S. papillosum, S. fuscum, S. girgensohnii, S. rubellum, S. angustifolium, S. cuspidatum, S. fallax, S. jensenii, S. lindbergii, S. majus, S. pulchrum, S. riparium, S. squarrosum,* and *S. wulfianum*). *Sphagnum imbricatum* was included twice, one sample prepared with leaves only and one using whole plants. The *S. jensenii* sample used whole plants. All other samples were prepared from leaves only, simulating commercial production. In the leaf-only samples, particles smaller and larger than leaves were removed from the samples using a series of screens of varying sizes. Some portions of central and branch stems remain.

Mixtures of *S. fuscum* and *S. magellanicum*, and *S. riparium* and *S. fuscum* were also prepared into board (using whole plants). Results of absorbency tests are included for comparative purposes. However, the tests for these mixtures were not replicated, and are not included in the statistical analysis for ranking.

■ Commercial Board
Mean of commercial board values, parameters for commercial quality control standards, and a ypical sample board

■ Section *Sphagnum*
Sphagnum imbricatum, S. magellanicum and *S. papillosum*

■ Section *Acutifolia*
Sphagnum fuscum, S. girgensohnii and *S. rubellum*

□ Section *Cuspidata*
Sphagnum angustifolium, S. cuspidatum, S. fallax, S. jensenii, S. lindbergii, S. majus, S. pulchrum, and *S. riparium* (emergent and submerged)

■ Section *Squarrosa*
Sphagnum squarrosum

▒ Section *Polyclada*
Sphagnum wulfianum

▥ 50/50 Mixture of two species

■ Whole Plant Treatment

Figure 3.2.6.1. Patterns identifying composition of individual boards in all figures. Commercial board results and handsheets made from species in different taxonomic sections (Sections *Sphagnum*, *Acutifolia*, *Cuspidata*, *Squarrosa*, and *Polyclada* are used here) are identified. Boards made with mixtures of species and boards made with whole plants are identified by pattern. Boards identified by solid patterns are made with screened leaves. Mixtures will be indicated using the section patterns of the two species used (all mixtures were also whole plant treatments).

Each of the sections of *Sphagnum*, and different treatments within a section, are given a consistent pattern in all figures throughout the text, as per figure 3.2.6.1. Using these patterns, the presence or absence of taxonomic trends are determined for all tests.

Drying power, GATS, and impact measurements were replicated three times if sufficient material is available. Retention capacity was determined once. Density, dry weight, and percent water content were calculated one to three times depending on amount of material available. Number of replicates is indicated in the results section as "n" for each species. The sixteen species and treatments were used for all tests on the principal boards. All other boards are excluded from these calculations of mean and standard deviation, including commercial boards. The means and standard deviations of the absorption tests for the above boards are the values used for ranking of absorptive ability. Other treatments are included in the figures for comparison only.

The following were calculated for each absorbency test and board characteristic:

1. Mean of individual board result
2. Standard deviation of individual board result (if n>1)
3. Mean of all principal boards (listed above)
4. Standard deviation of all principal boards (listed above)
5. Coefficient of Variation of mean of all principal boards (listed above)
   (100 X Standard Deviation/Mean)

All results are given in the format shown in figure 3.2.6.2.

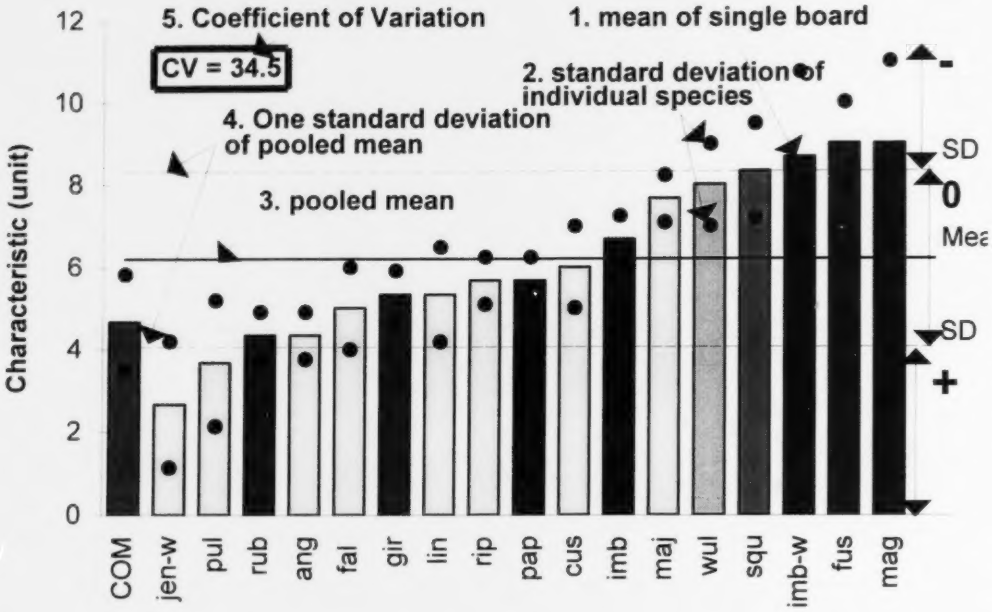


Figure 3.2.6.2: Hypothetical results of an absorbency test or morphology result, illustrating the layout of figures and how scores are designated in results section. COM = Commercial board. Species indicated by first three letters of specific epithet (species listed in figure 3.2.6.1). W = board made from whole plants. Subgeneric sections and mixtures represented by patterns on bars (figure 3.2.6.1.).

For absorbency characteristics (GATS, drying power, impact and retention capacity), the species are listed in tables from most satisfactory to least satisfactory. The patterns of the bars in figures represent the subgeneric sections for identification of taxonomic trends. For measured characteristics (density, dry weight, and percent water content) the species are listed in ascending order. For comparison, mean commercial board values, commercial specifications and results from the sample board are shown first, when available.

Figures are separated into three parts using the standard deviation from the mean of the principal boards. Those results that are within one standard deviation from the mean are designated "0". Those that are more than one standard deviation from the mean are either "+" or "-". For absorbency characteristics, "+" indicates that the performance is superior, and "-" result is inferior. Since the species are listed in order from the superior performance most inferior performance, those species on the left hand side of the figure that are greater than one standard deviation from the mean score "+", and those on the right score "-". The exception to this was Impact, where 100% was scored as "+", since a better result is impossible to obtain. For descriptive characteristics, "+" and "-" do not necessarily imply superiority or inferiority. In the hypothetical example (figure 3.2.6.2) *Sphagnum jensenii,* and *S. pulchrum* score "+" and *S. imbricatum* (whole), *S. fuscum* and *S. magellanicum* score "-". *Sphagnum squarrosum* is equal to one standard deviation from the mean and the remainder within one standard deviation and are scored as "0". In the tables, species which do not meet or exceed commercial standards are shaded.

3.2.7 Determination of Rank Order of Species

Each absorbency characteristic has three possible scores, "+", "-" or "0". To determine rank of the principal boards, these scores are given numerical values. Only these three scores were used to determine rank rather than splitting the data into more categories, because the most important information to extract from this data is which species are the best for absorbent board. A score of "+" was given a value of 1 (superior performance), "-" a value of -1 (inferior performance), and "0" was given a value of 0 (average performance).

GATS, drying power and impact are the absorbency characteristics used. These characteristics are given equivalent weight in determining rank. Each absorbency test has a total possible score of one, and the highest possible score for any species is three. Retention capacity is not used in ranking as it is a characteristic of the fresh moss sample, not of the monospecific board. Both DP 120 and DP 30 are used in ranking. In order that drying power has the same weight as the other absorbency characteristics, the scores for DP 30 and DP 120 are divided by two, giving a total possible score for drying power of one.

3.3 Results

3.3.1 Gravimetric Absorbency Testing System (GATS)

All species of *Sphagnum* have a GATS score greater than the minimum for commercial acceptance (table 3.3.1.1). *Sphagnum magellanicum* and *S. riparium* (made with whole plants) and *S. fallax* have superior GATS values. *Sphagnum squarrosum, S. imbricatum* (whole) and *S. wulfianum* have inferior GATS scores. Species specific GATS ranged from 0.8% below the value for GATS in the sample commercially produced board, to 77% higher than commercially produced board (figure 3.3.1.1). Scores for GATS are not related to subgeneric division, since the five best performing species (discounting whole plant samples) contain representatives from the three largest sections (Sections *Sphagnum*, *Acutifolia* and *Cuspidata*). Only one species (*Sphagnum wulfianum*) scored less than mean commercial board production.

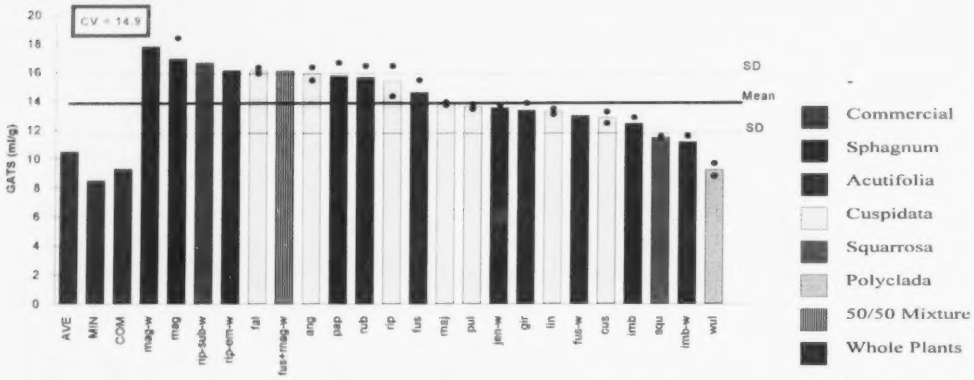


Figure: 3.3.1.1: Scores for GATS (ml·g^{-1}) of handsheets compared to commercial board. AVE = mean of 100 commercial boards. MIN = minimum requirements for acceptance of commercial board. COM = typical commercial board. Species are denoted by the first three letters in their specific epithet as in table 3.3.1.1 "W" refers to boards produced from the whole plant, other boards produced from the leaves only. Top and bottom line are one standard deviation above and below mean of boards in table 3.3.1.1 (centre line). Commercial boards were not included in mean. Closed circles are one standard deviation for the individual species. "CV" is the variation coefficient for boards in table 3.3.1.1.

Table 3.3.1.1: Scores for GATS in monospecific boards compared to average commercial board result, minimum requirement for commercial acceptance, and a typical commercial board result.

Rank Order	Species	Result	Mean (Std Dev)	n
	Commercial - ave	-	10.5	100
	Commercial - min	-	8.5	
	Commercial - sample	-	9.3	1
1	*S. magellanicum*	+	16.93 (1.45)	3
2	*S. fallax*	+	16.10 (0.20)	3
3	*S. angustifolium*	+	15.87 (0.45)	3
4	*S. papillosum*	0	15.73 (0.90)	3
5	*S. rubellum*	0	15.63 (0.78)	3
6	*S. riparium*	0	15.36 (1.06)	3
7	*S. fuscum*	0	14.59 (0.84)	3
8	*S. majus*	0	13.80 (0.10)	3
9	*S. pulchrum*	0	13.60 (0.17)	3
10	*S. jensenii* (w)	0	13.53 (0.15)	3
11	*S. girgensohnii*	0	13.34 (0.49)	3
12	*S. lindbergii*	0	13.26 (0.19)	3
13	*S. cuspidatum*	0	12.83 (0.40)	3
14	*S. imbricatum*	0	12.43 (0.40)	3
15	*S. squarrosum*	0	11.45 (0.07)	3
16	*S. imbricatum* (w)	-	11.15 (0.38)	3
17	*S. wulfianum*	-	9.22 (0.44)	3
	ALL		**13.81 (2.06)**	

3.3.2 Drying Power

The drying power of monospecific board made from fresh material is greatly superior to that of commercial board in all cases (figure 3.3.2.1).

Whole plant treatments do not affect the DP 30 of *S. fuscum*, but drying power is detrimentally affected by whole plant treatments in *S. riparium* and *S. magellanicum* (figure 3.3.2.1).

Superior performance for DP 30 is not related to subgeneric divisions, with the five best species having representatives from each of the three largest sections (Sections *Sphagnum*, *Cuspidata*, and *Acutifolia*) (table 3.3.2.1). Inferior performance for DP 30 is correlated to subgeneric groupings (figure 3.3.2.1). Most species in Section *Cuspidata*, and *S. squarrosum* have a high (inferior) drying power.

High values for DP 120 are related to subgeneric sections (figure 3.3.2.2). All of the species with a DP 120 above the mean (inferior drying power) occurred in Section *Cuspidata*. Only one species in Section *Cuspidata*, *S.* fallax, scored below the mean (superior drying power). Species in Sections *Sphagnum* and *Acutifolia* have a superior drying power. The four best species for DP 120 (*Sphagnum magellanicum, S. fuscum, S. girgensohnii* and *S. papillosum*) are considered to be approximately equivalent, since their standard deviations overlap by greater than 10% (table 3.3.2.2).

Whole plant treatment is not related to DP 120 in Sections *Sphagnum* and *Acutifolia*, but is detrimental in Section *Cuspidata*. There is no difference in score between *S. imbricatum, S. magellanicum* and *S. fuscum* board made with leaves only and with whole plants (table 3.3.2.2). *Sphagnum riparium* board made with whole plants is inferior to that made with leaves only (figure 3.3.2.2).

Sphagnum fuscum, magellanicum, and *papillosum* are superior performers for *DP* 30, and *S. majus* and *S. squarrosum* are inferior performers. *Sphagnum magellanicum* (whole plants or leaves only), *S. fuscum* (whole plants or leaves only), *S. girgensohnii* and *S. papillosum* are superior performers for DP 120 and *S. pulchrum, S. cuspidatum and S. majus* are inferior performers for drying power (120 minutes).

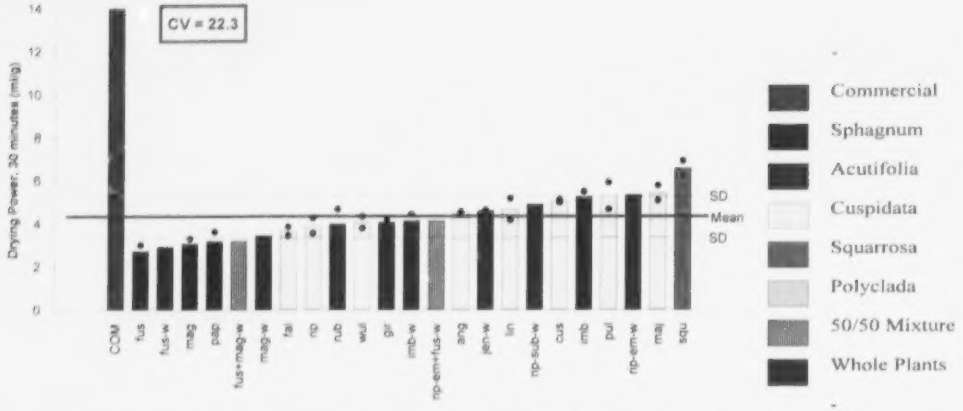


Figure 3.3.2.1. Drying Power of *Sphagnum* board measured after 30 minutes in ml g^{-1}. Species are denoted by the first three letters in their specific epithet as in table 3.3.2.1. "W" refers to boards produced from the whole plant, other boards produced from the leaves only. Top and bottom line are one standard deviation above and below the mean of species in table 3.3.2.1 (centre line). Commercial boards were not included in the mean. Closed circles are one standard deviation for the individual species (n=3). For Commercial board, n=1. "CV" is the coefficient of variation.

Table 3.3.2.1: Drying Power measured after 30 minutes in monospecific boards compared to a typical commercial board. Scores are grouped according to whether they are above one standard deviation from the mean of all monospecific board (+), below one standard deviation (-) or within or equal to one standard deviation (0). Ranked from best performance to lowest performance.

Rank Order	Species	Result	Mean (Std Dev)	n
	Commercial - Sample	-	14.00	1
1	*S. fuscum*	+	2.72 (0.28)	3
2	*S. magellanicum*	+	3.07 (0.35)	3
3	*S. papillosum*	+	3.17 (0.21)	3
4	*S. fallax*	0	3.63 (0.21)	3
5	*S. riparium*	0	3.89 (0.67)	3
6	*S. rubellum*	0	3.97 (0.35)	3
7	*S. wulfianum*	0	4.04 (0.34)	2
8	*S. girgensohnii*	0	4.05 (0.04)	2
9	*S. imbricatum* (w)	0	4.13 (0.35)	3
10	*S. angustifolium*	0	4.50 (0.44)	3
11	*S. jensenii* (w)	0	4.57 (0.03)	3
12	*S. lindbergii*	0	4.65 (0.49)	3
13	*S. cuspidatum*	0	5.03 (0.06)	3
14	*S. imbricatum*	0	5.21 (0.25)	3
15	*S. pulchrum*	0	5.27 (0.29)	3
16	*S. majus*	-	5.40 (0.10)	3
17	*S. squarrosum*	-	6.55 (0.62)	2
	ALL		**4.31 (0.96)**	**48**

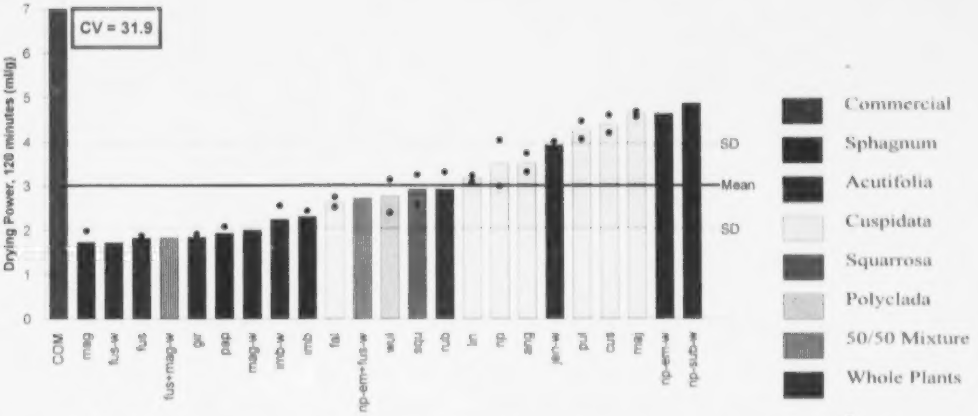


Figure 3.3.2.2. Drying Power (ml g^{-1}) of monospecific *Sphagnum* board measured after 120 minutes. Species are denoted by the first three letters in their specific epithet as in table 3.3.2.2. "W" refers to boards produced from the whole plant, other boards produced from the leaves only. Top and bottom line are one standard deviation above and below the mean of species in table 3.3.2.2 (centre line). Closed circles are one standard deviation for the individual species (n=3). "CV" is the coefficient of variation.

Table 3.3.2.2: Drying Power measured after 120 minutes in monospecific boards compared to a typical commercial board. Scores are grouped according to whether they are above one standard deviation from the mean of all monospecific board (+), below one standard deviation (-) or within or equal to one standard deviation (0). Ranked from best performance to lowest performance. n = number of replications.

Rank Order	Species	Result	Mean (Std Dev)	n
	Commercial	-	9	1
1	*S. magellanicum*	+	1.73 (0.25)	3
2	*S. fuscum*	+	1.83 (0.05)	3
3	*S. girgensohnii*	+	1.85 (0.057)	2
4	*S. papillosum*	+	1.93 (0.15)	3
5	*S. imbricatum* (w)	0	2.25 (0.31)	3
6	*S. imbricatum*	0	2.31 (0.13)	3
7	*S. fallax*	0	2.63 (0.12)	3
8	*S. wulfianum*	0	2.77 (0.37)	2
9	*S. squarrosum*	0	2.93 (0.33)	2
10	*S. rubellum*	0	2.93 (0.38)	3
11	*S. lindbergii*	0	3.17 (0.078)	3
12	*S. riparium*	0	3.52 (0.52)	3
13	*S. angustifolium*	0	3.53 (0.21)	3
14	*S. jensenii* (w)	0	3.93 (0.086)	3
15	*S. pulchrum*	-	4.27 (0.21)	3
16	*S. cuspidatum*	-	4.40 (0.20)	3
17	*S. majus*	-	4.63 (0.058)	3
	ALL		**3.01 (0.96)**	**48**

3.3.3 Impact

Sixty-five percent of species have an impact of 100%, the optimal result (table 3.3.3.1). Impact is not related to subgeneric divisions of *Sphagnum*, since the species that scored 100% have representatives from the three major taxonomic Sections (*Sphagnum*, *Acutifolia* and *Cuspidata*) (figure 3.3.3.1). Whole plant treatment has a detrimental effect on impact in *S. imbricatum*.

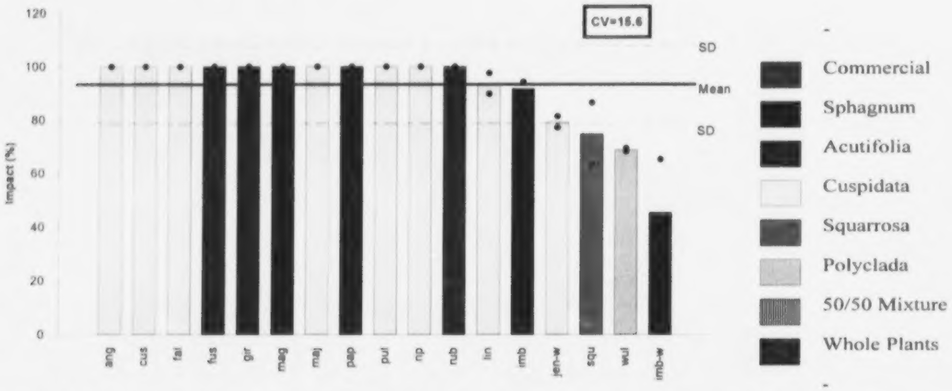


Figure 3.3.3.1: Impact (%) of *Sphagnum* boards. Each species is represented by the first three letters of the specific epithet, as per table 3.3.3.1. Taxonomic groups are as per figure 3.2.6.1. Center line is the mean of the Impact of all boards in table 3.3.3.1. Bottom line is one Standard Deviation below the mean. Closed circles are Standard Deviations for each individual species (n=3). "CV" = Coefficient of Variation.

Table 3.3.3.1: Impact of *Sphagnum* boards. Result (+) is an Impact of 100%. Result (0) is less than 100%, but greater than 78.71% (one Standard Deviation below the mean). Result (-) is an Impact less than 78.71%. n = number of replications.

RANK ORDER	SPECIES	RESULT	MEAN (STD DEV)	n
1	*S. angustifolium*	+	100 (0)	3
1	*S. cuspidatum*	+	100 (0)	3
1	*S. fallax*	+	100 (0)	3
1	*S. fuscum*	+	100 (0)	3
1	*S. girgensohnii*	+	100 (0)	2
1	*S. magellanicum*	+	100 (0)	3
1	*S. majus*	+	100 (0)	3
1	*S. papillosum*	+	100 (0)	3
1	*S. pulchrum*	+	100 (0)	3
1	*S. riparium*	+	100 (0)	2
1	*S. rubellum*	+	100 (0)	3
2	*S. lindbergii*	0	93.65 (3.88)	2
3	*S. imbricatum*	0	91.8 (2.40)	2
4	*S. jensenii* (w)	0	79.25 (2.05)	2
5	*S. squarrosum*	-	74.80 (11.60)	2
6	*S. wulfianum*	-	68.85 (0.64)	2
7	*S. imbricatum* (w)	-	45.35 (19.87)	2
	ALL		**93.20 (14.49)**	**43**

3.3.4 Retention Capacity

Most of the monospecific fresh moss samples have a higher retention capacity than the mined peat material from which commercial board is made. No figures are available for the retention capacity of the *Sphagnum* from which the sample commercial board was made. High retention capacity is preferable to low retention capacity.

Retention capacity when 1200g of weight is placed on the peat sample (RC 1200g) has the least variation among species and maximum retention capacity has the most variation among species (figure 3.3.4.1). For instance, RC Max of *Sphagnum fallax* is more than double that of *S. wulfianum*, while the RC 1200g for *S. fallax* is 40% higher than that of *S. wulfianum*.

Maximum retention capacity is not related to subgeneric groupings, as the three major Sections of *Sphagnum* (*Acutifolia*, *Sphagnum* and *Cuspidata*) are represented in the four highest scoring species (figure 3.3.4.1). No patterns relating to subgeneric Sections can be discerned in RC 300g or RC 1200g since the three major sections are represented in the three highest scoring species for RC 300g and the five highest scoring species for RC 1200g (figure 3.3.4.4).

The amount of water squeezed out under moderate pressure (figure 3.3.4.2 and figure 3.3.4.3) is related to subgeneric groupings. Section *Cuspidata* tends to have less water squeezed out than Section *Sphagnum*. The species in Section *Acutifolia* do not follow any discernible pattern relating to amount of water squeezed out under moderate pressure.

In *Sphagnum squarrosum*, more than three times the water is squeezed out under moderate pressure (300g of weight) in comparison to *S. wulfianum* (figure 3.3.4.2). Species with a high retention capacity do not necessarily have the ability to retain that water under pressure. *Sphagnum squarrosum* has a high RC Max (figure 3.3.4.1), but more than 50% of the water is lost when placed under moderate pressure (300g of weight placed on sample) (figure 3.3.4.3a).

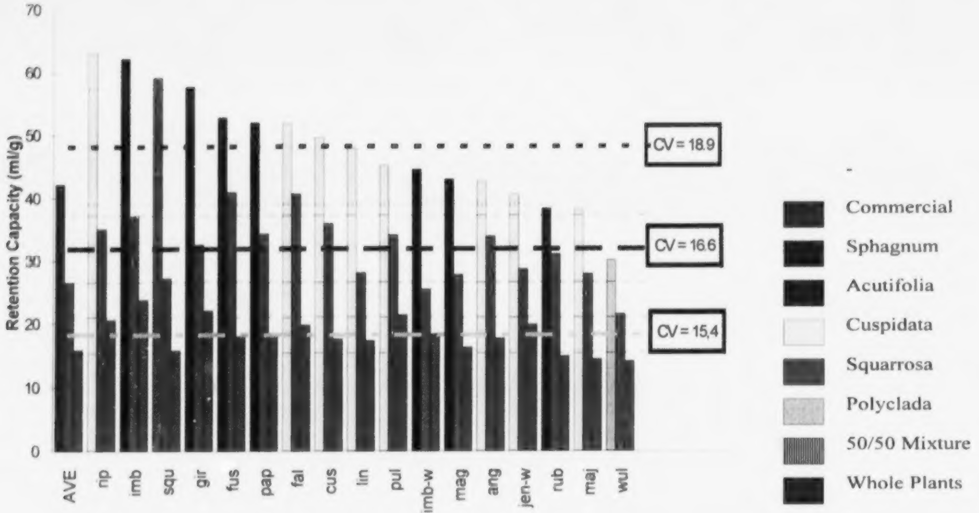


Figure 3.3.4.1: Retention Capacity of peat samples used to make monospecific handsheets compared to material used in commercial board production (AVE). Species are represented by the first three letters of the specific epithet as listed in table 3.3.4.1. For each species, the first bar is RC MAX, the second is RC 300g, the third is RC 1200g. Horizontal lines represent the mean and standard deviations of the results of all species for each test. Short dashes = RC MAX, long dashes = RC 300g, intermittent dashes RC 1200g. In each group, upper line is one Standard Deviation above the mean for that test. Lower line is one Standard Deviation below the mean for that test. CV = Variation Coefficient.

Table 3.3.4.1: Scores of Retention Capacity of peat samples. 0 = within or equal to one Standard Deviation (SD) from the mean of all samples. More than one SD above the mean = "+", and more than one SD below the mean = "-". N = 1 for all species (except commercial where n=100.

SPECIES	RC MAX	RC 300g	RC 1200g	RC MAX - RC 300g	RC MAX - RC 300g (%)	RC MAX - RC 1200g (%)
Commercial (mean)	0	0	0	0	0	0
S. riparium	+	0	0	-	-	-
S. imbricatum	+	+	+	-	0	-
S. squarrosum	+	0	0	-	-	0
S. girgensohnii	+	0	+	-	-	0
S. fuscum	0	+	0	0	+	0
S. papillosum	0	0	0	0	0	0
S. fallax	0	+	0	0	+	0
S. cuspidatum	0	0	0	0	0	0
S. lindbergii	0	0	0	0	0	0
S. pulchrum	0	0	+	0	0	+
S. imbricatum - w	0	-	0	0	0	0
S. magellanicum	0	0	0	0	0	0
S. angustifolium	0	0	0	+	+	0
S. jensenii - w	0	0	0	0	0	+
S. rubellum	-	0	-	+	+	0
S. majus	-	0	-	0	0	0
S. wulfianum	-	-	-	+	0	+

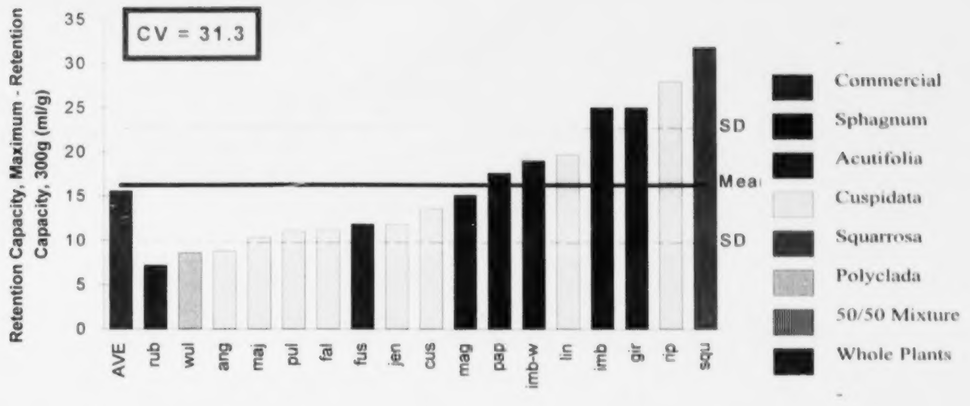


Figure 3.3.4.2: Difference between Maximum Retention Capacity and Retention Capacity under 300g of weight of monospecific peat samples. Species are denoted by first three letters of their specific epithet, as per table 3.3.4.1. AVE = Mean of commercial board. CV = Variation Coefficient. SD = Standard Deviation for all species. Mean = Mean of all species.

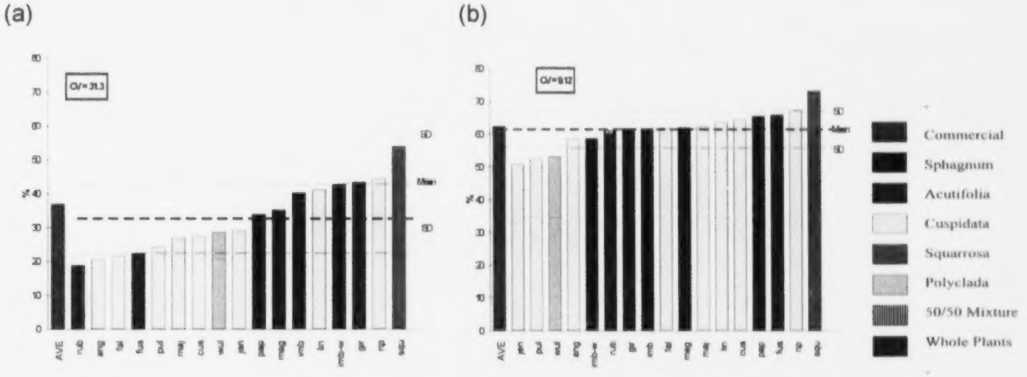


Figure 3.3.4.3: Proportion of water squeezed out of monospecific peat samples due to (a) 300g of weight placed on the sample and (b) 1200g of weight placed on the sample. Species are denoted by first three letters of their specific epithet, as per table 3.3.4.1. AVE = Mean of commercial board. CV = Variation Coefficient. SD = Standard Deviation for all species. Mean = Mean of all species.

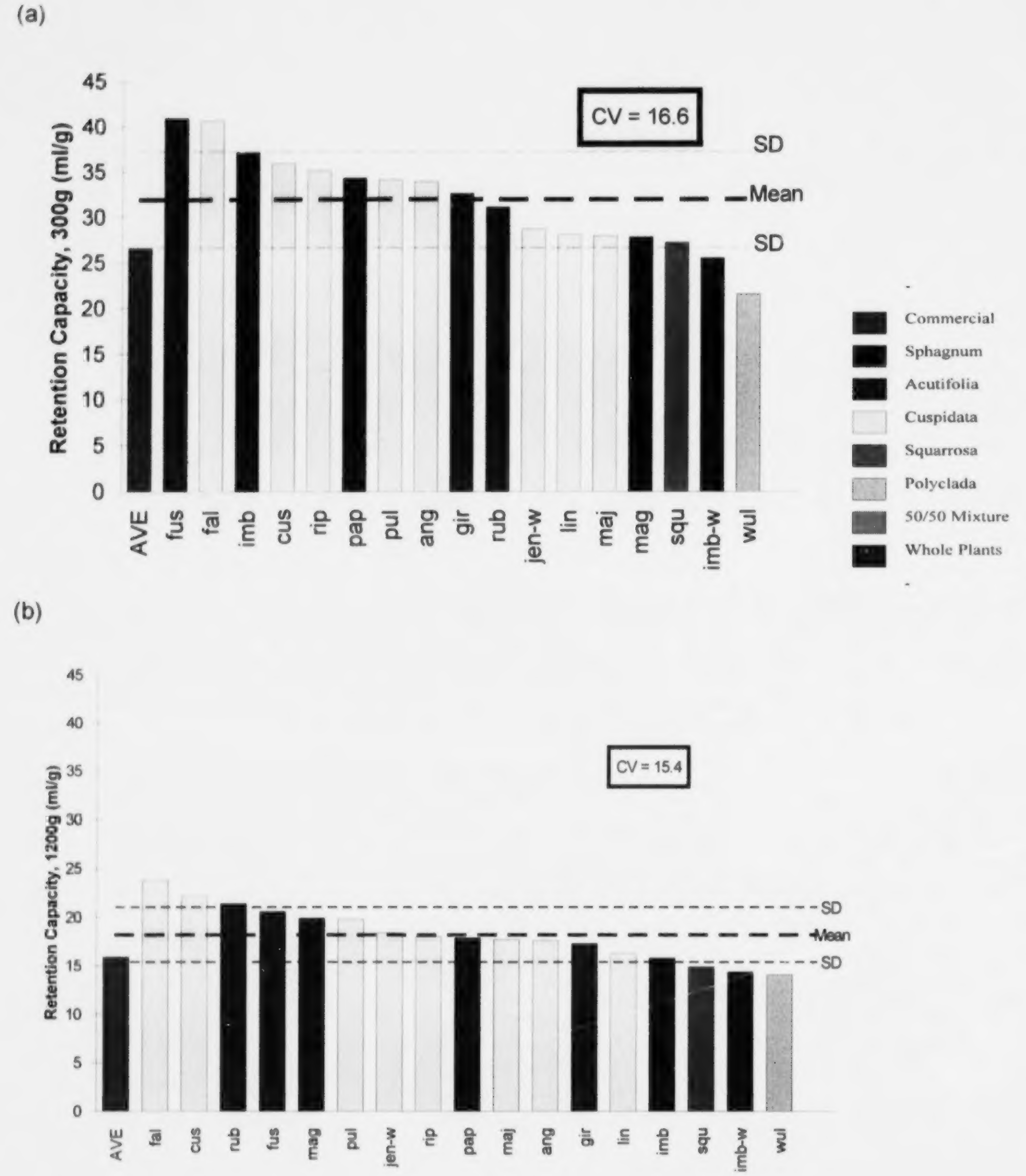


Figure 3.3.4.4: Retention Capacity of monospecific peat samples when 300 g of mass (a) and 1200 g of mass (b) are placed on sample. Species are denoted by the first three letters of the specific epithet as per table 3.3.4.1. W = Material from which boards manufactured with whole plants were made. AVE = Mean of commercial board. Centre line is mean of the Retention Capacity of all monospecific samples. Upper and lower lines are one Standard Deviation (SD) above and below the mean. CV = Variation Coefficient.

3.3.5 Density, Dry Weight and Percent Water Content

Density, dry weight and percent water content are descriptive characteristics of the board, and therefore a positive or negative score indicates only whether the figure is more than one Standard Deviation above or below the mean of all the monospecific *Sphagnum* boards (tables 3.3.5.1, 3.3.5.2, and 3.3.5.3). These scores are not performance indicators.

Boards manufactured from whole plants have a lower density than boards made with leaves only. *Sphagnum imbricatum* manufactured from whole plants is 27.5% less dense than *S. imbricatum* manufactured with leaves only (figure 3.3.5.1). *Sphagnum jensenii,* the species in Section *Cuspidata* manufactured from whole plants has the lowest density. *Sphagnum* board manufactured from leaves of species in the Sections *Acutifolia* and *Sphagnum* tend to be more dense than those in most of the species in Sections *Cuspidata*, *Squarrosa* and *Polyclada*; however, the species in Section *Cuspidata* are variable. There is a relationship between this variation and the habitat in which the species grow. Of those *Cuspidata* species that have a density below the mean, 80% occur in pools. Of those that have a density above the mean, none occur in pools.

The amount of variation in dry weight was one sixth that seen in the density, and one half that seen in the percent water content (figures 3.3.5.1, 3.3.5.2 and 3.3.5.3). This is because during the manufacture of handsheets, the amount of peat material used per sheet is measured by mass, not by volume. The density will vary with the degree to which the species compacts in the handsheet, and the percent hygroscopic water content depends on how much moisture evaporates from the handsheet before the tests are performed. For adequate comparison between species, the percent hygroscopic water content should not be widely variable (the standard used is between 12 and 16%).

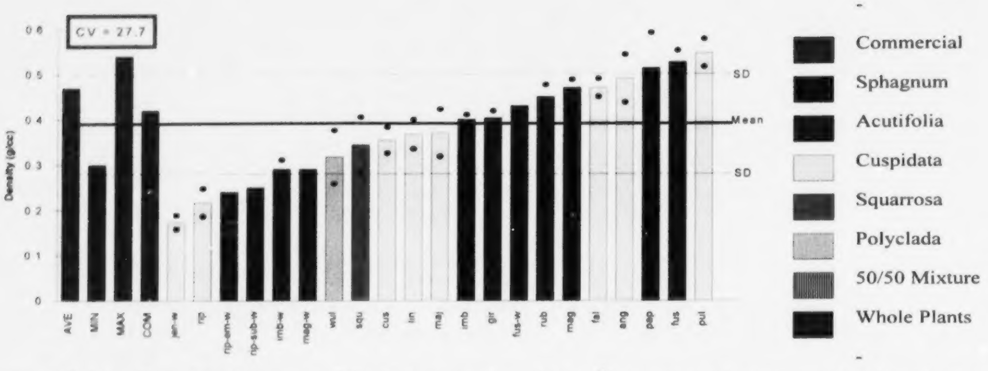


Figure: 3.3.5.1: Density of monospecific *Sphagnum* board ($g m^{-2}$) compared to commercial; board values (AVE = mean, MAX and MIN = Maximum and Minimum commercially acceptable, COM = Sample commercial board) Species are represented by the first three letters of the specific epithet as per table 3.3.5.1. W = boards made with whole plants; other boards are made from leaves only. Centre line is mean of Density of all monospecific *Sphagnum* boards in table 3.3.5.1 (Commercial board is excluded). Top line is one Standard Deviation (SD) above this mean; bottom line is one Standard Deviation below this mean. Closed circles are one Standard Deviation above and below the mean for the Dry Weight of the individual monospecific *Sphagnum* boards. CV = Variation Coefficient.

Table 3.3.5.1: Density of monospecific *Sphagnum* boards compared to commercial board (Mean, Minimum and Maximum acceptable, and sample board). A positive (+) score indicates the result was more than one Standard Deviation above the mean of the Density of all monospecific boards. A negative (-) score indicates the result was more than one Standard Deviation below the mean of the Density of all monospecific boards. Commercial board was not included in calculation of Mean and Standard Deviation. W = board made with whole plants; other boards are made with leaves only. Shading indicates species not within commercial specifications.

RANK ORDER	SPECIES	SCORE	MEAN (STD DEV)	n
	Commercial - Mean	0	0.47	100
	Commercial - Minimum		0.30	
	Commercial - Maximum		0.54	
	Commercial - Sample	+	0.42 (0.02)	3
1	*S. jensenii* - w	-	0.17 (0.019)	3
2	*S. riparium*	-	0.22 (0.025)	3
3	*S. imbricatum* - w	0	0.29 (0.031)	3
4	*S. wulfianum*	0	0.32 (0.038)	3
5	*S. squarrosum*	0	0.34 (0.040)	3
6	*S. cuspidatum*	0	0.35 (0.038)	3
7	*S. lindbergii*	0	0.37 (0.040)	3
8	*S. majus*	0	0.37 (0.042)	3
9	*S. imbricatum*	0	0.40 (0.041)	3
10	*S. girgensohnii*	0	0.40 (0.042)	3
11	*S. rubellum*	0	0.45 (0.048)	3
12	*S. magellanicum*	0	0.47 (0.049)	3
13	*S. fallax*	0	0.47 (0.049)	3
14	*S. angustifolium*	0	0.49 (0.054)	3
15	*S. papillosum*	+	0.51 (0.059)	3
16	*S. fuscum*	+	0.53 (0.055)	3
17	*S. pulchrum*	+	0.55 (0.058)	3
	ALL		0.39 (0.011)	51

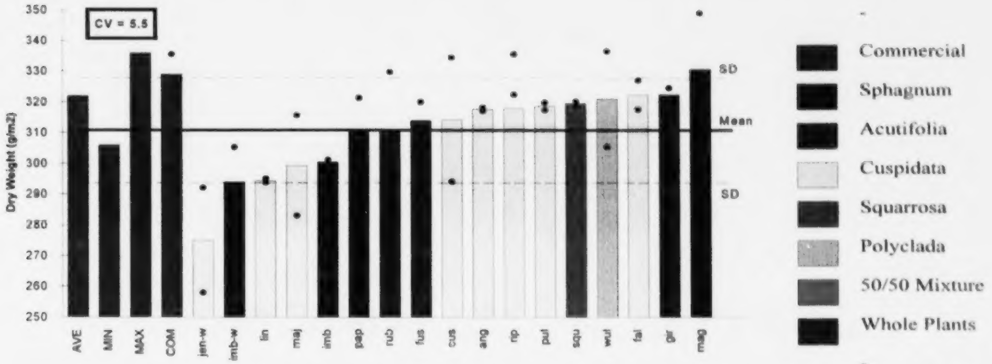


Figure 3.3.5.2: Dry weight of *Sphagnum* board ($g m^{-2}$). Species are represented by the first three letters of the specific epithet as per table 3.3.5.2. W = boards made with whole plants; other boards are made from leaves only. AVE = Mean commercial board result (n=100). MIN and MAX = Minimum and maximum acceptable for commercial board. COM = Commercial board from production run on June 11, 1993. Centre line is mean of Dry Weight of all monospecific *Sphagnum* boards in table 3.3.5.2 (Commercial board is excluded). Top line is one Standard Deviation (SD) above this mean; bottom line is one Standard Deviation below this mean. Closed circles are one Standard Deviation above and below the mean for the Dry Weight of the individual monospecific *Sphagnum* boards. CV = Variation Coefficient.

Table 3.3.5.2: Dry Weight of monospecific *Sphagnum* boards compared to commercial board figures (Mean, Minimum, Maximum and sample board). A positive (+) score indicates the result was more than one Standard Deviation above the mean of the Dry Weight of all monospecific boards. A negative (-) score indicates the result was more than one Standard Deviation below the mean of the Dry Weight of all monospecific boards. Commercial board was not included in calculation of Mean and Standard Deviation. W = board made with whole plants; other boards are made with leaves only. Shading indicates those boards that do not meet commercial requirements.

RANK ORDER	SPECIES	SCORE	MEAN (STD DEV)	n
	Commercial - Mean	0	322	100
	Commercial - Minimum	0	306	
	Commercial - Maximum	+	336	
	Commercial - Sample	+	329.0 (6.6)	3
1	*S. jensenii* - w	-	280.3 (11.02)	3
2	*S. imbricatum* - w	-	294.0 (11.3)	2
3	*S. lindbergii*	-	294.5 (0.7)	2
4	*S. majus*	0	299.3 (16.3)	3
5	*S. imbricatum*	0	300.5 (0.7)	2
6	*S. papillosum*	0	310.7 (10.6)	3
7	*S. rubellum*	0	311.0 (18.7)	3
8	*S. fuscum*	0	314.0 (6.0)	3
9	*S. cuspidatum*	0	314.3 (20.1)	3
10	*S. angustifolium*	0	317.7 (0.6)	3
11	*S. riparium*	0	318.0	1
12	*S. pulchrum*	0	318.7 (1.2)	3
13	*S. squarrosum*	0	319.5 (0.7)	2
14	*S. wulfianum*	0	321.0 (15.6)	2
15	*S. fallax*	0	322.3 (4.7)	3
16	*S. girgensohnii*	0	322.5 (2.1)	2
17	*S. magellanicum*	+	330.7 (18.3)	3
	ALL		**310.8 (17.1)**	**43**

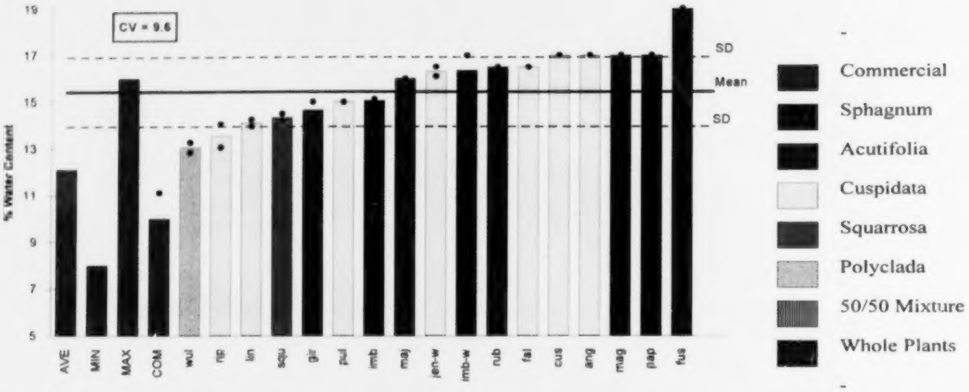


Figure 3.3.5.3: Percent Water Content of *Sphagnum*. Species are represented by the first three letters of the specific epithet as per table 3.3.5.3. W = boards made with whole plants; other boards are made from leaves only. AVE = Mean of commercial boards (n=100). MIN = Minimum and MAX = Maximum commercially acceptable. COM = Typical commercial board. Centre line is mean of Percent Water Content of all monospecific *Sphagnum* boards (Commercial board is excluded). Top line is one Standard Deviation (SD) above this mean; bottom line is one Standard Deviation below this mean. Closed circles are one Standard Deviation above and below the mean for the Percent Water Content of the individual monospecific *Sphagnum* boards. CV = Coefficient of Variation.

Table 3.3.5.3: Percent Water Content of monospecific *Sphagnum* boards and values for commercial board (Mean, Minimum acceptable, Maximum acceptable and Sample board). A positive (+) score indicates the result was more than one Standard Deviation above the mean of the Percent Water Content of all monospecific boards. A negative (-) score indicates the result was more than one Standard Deviation below the mean of the Dry Weight of all monospecific boards. Commercial board was not included in calculation of Mean and Standard Deviation. W = board made with whole plants; other boards are made with leaves only. n = number of replicates.

RANK ORDER	SPECIES	SCORE	MEAN (STD DEV)	n
	Commercial - Mean	-	12.1	100
	Commercial - Minimum	-	8.0	
	Commercial - Maximum	0	16.0	
	Commercial - Sample	-	10.0(1.10)	3
1	*S. wulfianum*	-	13.1(0.21)	2
2	*S. riparium*	-	13.6(0.49)	2
3	*S. lindbergii*	-	14.1(0.14)	2
4	*S. squarrosum*	0	14.3(0.15)	3
5	*S. girgensohnii*	0	14.7(0.35)	2
6	*S. pulchrum*	0	15	1
7	*S. imbricatum*	0	15.1(0.071)	2
8	*S. majus*	0	16	1
9	*S. jensenii-w*	0	16.3(0.20)	3
10	*S. imbricatum-w*	0	16.4(0.64)	2
11	*S. rubellum*	0	16.5	1
12	*S. fallax*	0	16.5	1
13	*S. cuspidatum*	0	17	1
14	*S. angustifolium*	0	17	1
151	*S. magellanicum*	0	17	1
16	*S. papillosum*	0	17	1
17	*S. fuscum*	+	19	1
	ALL		15.8 (1.54)	17

3.3.6 Rank Order Of Species According To Absorbency Characteristics

The absorbency characteristics used in ranking are GATS, drying power and impact. The inclusion of impact did not affect the rank for the top 50% of the species, but did affect those in the lower 50% (table 3.3.6.2). This is because all of the top performing species had an impact of 100%; therefore impact does not have an affect on the ranking for superior performing species.

Three quarters of the species tested have a better absorbency rating than commercial board. *Sphagnum magellanicum* is the best species for use in *Sphagnum* board. Board manufactured from *S. wulfianum* has the lowest absorbency performance. Board performance is not related to subgeneric groupings, since those species which ranked first and second contain members of Sections *Sphagnum*, *Acutifolia* and *Cuspidata* (table 3.3.6.1 and figure 3.3.6.1).

The effect of whole plant treatments is related to taxonomic groups. In *S. fuscum*, (Section *Acutifolia*) the whole plant treatment has no effect on absorbency (table 3.3.6.3). In species of Section *Sphagnum*, the whole plant treatment decreases GATS in *S. imbricatum* and decreases drying power in *S. magellanicum*. When *S. fuscum* is added to the whole plant treatment of *S. magellanicum*, there is no loss of absorbency. In *S. riparium* (Section *Cuspidata*) the whole plant treatment increases GATS and decreases drying power. These effects in the different sections are likely related to stem morphology.

Table 3.3.6.1: *Sphagnum* species in order of highest performance on absorbency tests (GATS, Drying Power and Impact) to lowest performing. For GATS, a score of 0 = within one Standard Deviation (SD) to the mean of all species; 1 = greater than or equal to one SD above the mean; -1 = greater than or equal to one SD below the mean. For Drying Power, 0 = within one Standard Deviation to the mean of all species; 0.5 = greater than one SD below the mean; -0.5 = greater than one SD above the mean. For Impact, 1 = 100%; 0 = between 100% and one SD below the mean; and -1 = less than one SD below the mean.

RANK ORDER	SPECIES	SECTION	GATS Score	DP 30 Score	DP 120 Score	IMPACT Score	TOTAL SCORE
6	Commercial Sample		-1	0.5	0.5	0	0
1	*S. magellanicum*	*Sphagnum*	1	0.5	0.5	1	3
2	*S. angustifolium*	*Cuspidata*	1	0	0	1	2
2	*S. fallax*	*Cuspidata*	1	0	0	1	2
2	*S. fuscum*	*Acutifolia*	0	0.5	0.5	1	2
2	*S. papillosum*	*Sphagnum*	0	0.5	0.5	1	2
3	*S. girgensohnii*	*Acutifolia*	0	0	0.5	1	1.5
4	*S. riparium*	*Cuspidata*	0	0	0	1	1
4	*S. rubellum*	*Acutifolia*	0	0	0	1	1
5	*S. cuspidatum*	*Cuspidata*	0	0	-0.5	1	0.5
5	*S. pulchrum*	*Cuspidata*	0	0	-0.5	1	0.5
6	*S. majus*	*Cuspidata*	0	-0.5	-0.5	1	0
6	*S. imbricatum*	*Sphagnum*	0	0	0	0	0
6	*S. lindbergii*	*Cuspidata*	0	0	0	0	0
7	*S. jensenii* - w	*Cuspidata*	0	0	-0.5	0	-0.5
8	*S. squarrosum*	*Squarrosa*	0	-0.5	0	-1	-1.5
9	*S. imbricatum* - w	*Sphagnum*	-1	0	0	-1	-2
9	*S. wulfianum*	*Polyclada*	-1	0	0	-1	-2

Table 3.3.6.2: A comparison between rankings when considering absorbency characteristics alone or in combination.

SPECIES	GATS, DP and IMPACT	GATS	DP	IMPACT	GATS and DP
Commercial Sample	6	3	1	2	4
S. magellanicum	**1**	1	1	1	1
S. angustifolium	**2**	1	3	1	2
S. fallax	**2**	1	3	1	2
S. fuscum	**2**	2	1	1	2
S. papillosum	**2**	2	1	1	2
S. girgensohnii	**3**	2	2	1	3
S. riparium	**4**	2	3	1	4
S. rubellum	**4**	2	3	1	4
S. cuspidatum	**5**	2	4	1	5
S. pulchrum	**5**	2	4	1	5
S. imbricatum	**6**	2	3	2	4
S. lindbergii	**6**	2	3	2	4
S. majus	**6**	2	5	1	6
S. jensenii - w	**7**	2	4	2	5
S. squarrosum	**8**	2	4	3	5
S. imbricatum - w	**9**	3	3	3	6
S. wulfianum	**9**	3	3	3	6

Table 3.3.6.3: Absorbency scores of boards made of leaves only compared with boards made with whole plants, and scores of one mixture made with whole plants.

Species	GATS Score	DP 30 Score	DP 120 Score	Total
S. magellanicum	1	0.5	0.5	**2**
S. magellanicum - w	1	0	0.5	**1.5**
S. fuscum	0	0.5	0.5	**1**
S. fuscum - w	0	0.5	0.5	**1**
S. riparium	0	0	0	**0**
S. riparium - w	1	-0.5	-0.5	**0**
S. imbricatum	0	0	0	**0**
S. imbricatum - w	-1	0	0	**-1**
S. fuscum & *S. magellanicum* - w	1	0.5	0.5	**2**

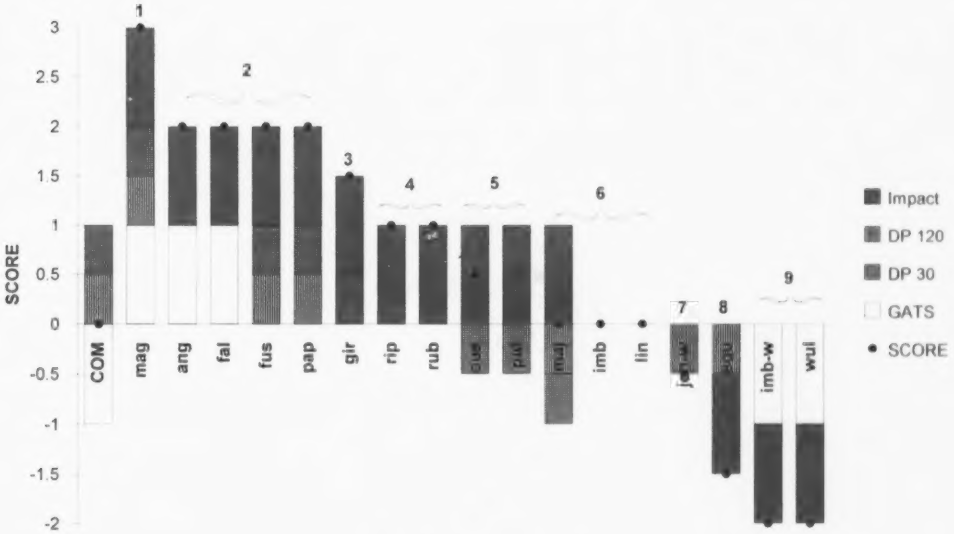


Figure 3.3.6.1: *Sphagnum* species ranked according to performance on the absorbency tests GATS, Drying Power and Impact. Species are represented by the first three letters of the specific epithet. Sections of *Sphagnum* are as per table 3.3.6.1. COM = Commercial board from production run on June 11, 1993.

3.3.7 Coefficient of Variation

The coefficient of variation (CV) is used to compare the variation between groups that have different means. A low CV indicates a lesser amount of variation than a high CV. A large amount of variation between species facilitates separation into groups. For instance, with the impact test, variation between species is low. This makes it difficult to determine which factors are responsible for a high impact, since most species have a high impact. DP 120 has 43% more variation than DP 30. DP 120 is therefore a better indicator of determining which species is best for drying power than is DP 30, since there is a wider variation between species (table 3.3.7.1).

To maximize the variability between species for Retention Capacity, the difference between RC Max and RC 300g is used in addition to the normal retention capacity measurements.

In the variation between the board characteristics (table 3.3.7.2), dry weight shows little variation. This is because the amount of *Sphagnum* used per handsheet is measured by weight, not by volume. Each handsheet is a standard area, but not necessarily a standard depth. The depth, and thus the density, will vary according to qualities of the *Sphagnum*. For instance, stems are not crushed in calendering, and therefore boards containing a higher percentage of stems will be thicker, and thus less dense.

Percent water content also has little variation (table 3.3.7.2). This is because the handsheets are dried and conditioned to approximately 12% hygroscopic water by weight, so that water content has as small an effect on the results of the absorbency tests as possible. For GATS, a ratio is used to correct the result to a water content of 12%.

Table 3.3.7.1: Comparison of Coefficient of Variation (100 X One Standard Deviation / Mean) of all absorbency tests.

Test	*CV*
RC Max - RC 1200g	9.1
GATS	14.9
RC 1200g	15.4
Impact	15.6
RC 300g	16.6
RC Max	18.9
DP 30	22.3
RC Max - RC 300g	31.3
DP 120	31.9

Table 3.3.7.2: Coefficient of variation of board characteristics (100XSD/Mean).

Property	*CV*
Dry Weight	5.5
% Water Content	9.6
Density	27.7

3.4 Conclusions

According to the results of the *Sphagnum* board absorbency tests designed by Johnson & Johnson Research, the best species for use in *Sphagnum* board is *Sphagnum magellanicum*. If whole plants are used, a combination of *Sphagnum magellanicum* and *Sphagnum fuscum* gives equally good results. *Sphagnum magellanicum* board made with whole plants has a decrease in drying power as compared to board made from leaves only. The large stems of this species may disrupt the continuous water column important for drying power. *Sphagnum fuscum* has fine, easily bent stems. In a mixture of the two, there is more continuity, resulting in a better drying power than board made from whole plants of *S. magellanicum* only. Also because of the large stems, *S. magellanicum*, or a mixture containing *S. magellanicum*, has a higher GATS than *S. fuscum*.

All boards made with fresh, monospecific *Sphagnum*, regardless of species or treatment, have a greatly superior drying power over the commercial product. This is because Pr-SPTF-1 migrates poorly in the commercial product as it is blocked by the presence of fine particles (Yvon Levesque, pers. com.). The use of pure species would solve this problem.

Whole plant treatments of *S. riparium*, both submerged and emergent samples, had a high GATS, but also an inferior drying power compared to other pure species boards. Both whole plant samples have similar absorbencies. *Sphagnum riparium*, especially when growing in pools, has a high stem to leaf ratio. The result, when using whole plants, is a board with more air space than by using the screened leaves. This results in a high GATS, but the poor continuity results in a low drying power.

All species of *Sphagnum* have a GATS that is acceptable for commercial purposes. Water holding capacity of commercial board can be increased by up to 82% from current production with the use of fresh moss. Impact is also improved by use of fresh moss in *Sphagnum* board. Drying power greatly improves with monospecific handsheets. This is probably due to the small particles that are present in partly decomposed commercial peat. These particles block fluid migration in commercial board. As well, these particles take up space, decreasing GATS values.

3.5 Summary

- All absorbency characteristics of handsheets are superior to those of commercial board.
- *Sphagnum magellanicum* (leaves only) or a mixture of *S. magellanicum* and *S. fuscum* (whole plants) have superior absorbency.
- *Sphagnum imbricatum* (whole plants) and *S. wulfianum* have the poorest absorbency out of all the species tested.
- In *S. riparium* (Section *Cuspidata*), GATS is increased with the use of whole plants, while drying power is inferior in whole plant board as compared to board made with leaves only.
- In *S. fuscum*, (Section *Acutifolia*) the whole plant treatment does not affect absorbency.

  In *S. magellanicum*, (Section *Sphagnum*) GATS is not decreased with the use of whole plants, but drying power is inferior in the whole plant treatment compared to the leaves only treatment.

Chapter 4: Morphology of *Sphagnum*

4.1 Introduction

The genus *Sphagnum* has morphological features unique among the Bryophyta and all members of the genus share a similar basic morphology. Differences such as habit, size, stem morphology, stem and branch leaf shape, fibrils, placement of chlorophyllous cells in relation to hyaline cells, and pore patterns enable taxonomists to distinguish different species and sections of *Sphagnum* (e.g., Crum 1984). Members of Sections *Sphagnum, Acutifolia, Cuspidata, Squarrosa, and Polyclada* are represented in this study.

The absorbent board made by Johnson & Johnson is presently manufactured with leaves that have been screened from the rest of the plant. Most of the small organic particles resulting from decomposition present in the mined peat moss are also screened out. This study focuses on the morphological features of the leaves, since the stems are not included in commercial board manufacture. In some cases, boards made with whole plants were included for comparison. In the statistical analyses, the plant morphological features used for whole plant boards were the same as the leaves-only board (board properties were different).

The branch leaves of all species of *Sphagnum* have dimorphic cells. Chlorophyllous cells and hyaline cells are both present. The hyaline cells have pores and annular fibrils. Measurements were made on the branch leaves, and on the hyaline cell properties of the branch leaves.

A brief description of the pertinent morphology in each of the sections, especially leaf characteristics follows (from Crum, 1984). Habitat type is also included.

Section *Sphagnum*

S. imbricatum (=*S. austinii*), *S. magellanicum* and *S. papillosum*

The species in Section *Sphagnum* are large, robust plants with cucullate branch leaves and the cucullate (hooded) branch leaves are the most obvious feature identifying this group. Microscopically, the large cells with pores often occurring in threes at adjacent cell angles are conspicuous. *Sphagnum imbricatum* and *S. magellanicum* are both hummock species, while *S. papillosum* grows in extensive lawns. One difference in morphology among these three species that is not dealt with in this chapter is the ornamentation on the sidewalls of the hyaline cells. *Sphagnum magellanicum* is without ornamentation. *Sphagnum papillosum* is papillose on the sidewalls of the hyaline cells. *Sphagnum imbricatum* has comb fibrils (elongate thickenings on the inside of the hyaline wall located opposite to the chlorophyllous cells), which were conspicuous in the samples used.

Section *Acutifolia*

S. fuscum, S. girgensohnii, and *S. rubellum*

Species of Section *Acutifolia* have small hummock-forming plants. All of the *Acutifolia* species have branch leaves with the green cells exposed on the concave surface of the leaf, and this feature is most easily seen in a transverse section of a leaf. Branch leaves are small, and ovate to lanceolate. Pores are large and numerous.

Section *Cuspidata*

S. angustifolium, S. cuspidatum, S. fallax, S. jensenii, S. lindbergii, S. majus, S. pulchrum and *S. riparium*

Species of Section *Cuspidata* are usually found in hollows (*S. angustifolium*), or form low mounds on the edge of wet areas or open water (*S. fallax, S. lindbergii, S. pulchrum, S. riparium*), or grow submerged in water (*S. cuspidatum, S. majus, S. jensenii* and *S. riparium*). Branch leaves are ovate to lanceolate, and sometimes very long (e.g. *S. cuspidatum*). There is more variation in pores and pore patterns in this group than the other sections. The chlorophyllous cells are exposed on the convex surface of the leaf.

Section *Squarrosa*

S. squarrosum

The most obvious feature for identification of *Sphagnum squarrosum* is the large, squarrose leaves. The leaves are ovate to lanceolate or ovate to hastate, often broad at the base especially on spreading branch leaves. Hanging branch leaves are much more narrow. Pores are large, and are found on both sides of the leaf. *Sphagnum squarrosum* is often found in mineral rich habitats, where the water table fluctuates. Material used was collected in a wet area of a deciduous forest.

Section *Polyclada*

S. wulfianum

Sphagnum wulfianum is easily identified on one characteristic alone; branches are in fascicles of six to twelve, as opposed to two to five for all other species. The stem is dark brown to black in colour, and is stiff and wiry. Individual capitula of this species often extend above the carpet. The capitulum is large and dense. Stem leaves are small, and oblong-triangular. The leaves on the numerous hanging branches are very slender, and nearly white in colour. The hanging branches completely envelop the stem. *Sphagnum wulfianum* is a forest species. Pores are small and elliptical on the convex side of spreading branch leaves. Chlorophyllous cells have an equal, but narrow exposure on both sides of the leaf.

4.2 Materials and Methods

4.2.1 Morphological Measurements

Sampling Methods

For each species a sample of about fifteen litres was collected of fresh material from a single location. The depth of fresh material varied between species. From this sample population, approximately half a litre of material was set aside for morphological measurements. From this sub-sample, three individual plants were chosen at random.

From each of the individual plants, a single fascicle was removed from below the capitulum (approximately one to two centimetres from the top of the plant). From the fascicle, the spreading and hanging branches were separated. The spreading branches were stained with crystal violet and the leaves placed on a slide. A data sheet of morphological characters was filled out for each individual plant. Leaf size and curvature data were taken from the first ten mature leaves encountered on the slide that were undamaged so these measurements could be made (in some cases, less than ten leaves were measured). In some cases, ten measurements for curvature could not be made due to damage of the leaves. An exception was *S. fallax*, in which leaves from the board were measured, since individual plants were unavailable.

From the same sub-sample, another individual was chosen at random, and a single fascicle was selected as above. Hanging and spreading branch leaves were stained with crystal violet, placed on separate slides, and pore and fibril frequency data taken from the first ten mature leaves encountered on the slide. Frequency data were taken from the base, centre tip, and edge of the leaf.

Measurement Methods

Measurements were made using an eyepiece micrometer in an Olympus light microscope, then converting eyepiece units to micrometers. Measurements were made using 100X to 1000X magnification.

A. LEAF CHARACTERISTICS

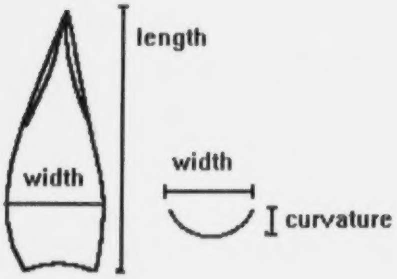


Figure 4.2.1.1. Method of leaf length, width and curvature measurements.

Size

Leaf length was measured from base to tip of leaf (figure 4.2.1.1). Leaf width was measured at the widest point in the leaf. During the measurements, leaves were placed on a slide with a coverslip. Leaves that appeared undamaged, and having a normal curvature were used.

Curvature

Leaf curvature was measured by focusing the microscope on mid-basal part of a leaf, and turning the knob to focus on the edges of the leaf. The number of units the focusing knob turned is the leaf curvature, and this value is converted to micrometers.

Shape

A representative leaf from those on the slide was chosen. Its shape and size were drawn to scale. First, the length of the leaf was represented by two points, then the width was measured at the base of the leaf, and at every ten eyepiece units. Additional features, such as inrolling of leaves at the tip were drawn in.

B. HYALINE CELL CHARACTERISTICS

The representative leaf used to determine shape was the leaf sample chosen to measure hyaline cell characteristics. With some species, it was possible to measure all characteristics using only one leaf, especially in groups with large distinct pores (Sections *Acutifolia*, *Sphagnum* and *Squarrosa*). In species where the pores were not as distinct, two leaves had to be used (Sections *Cuspidata* and *Polyclada*) in order to obtain pore data from the concave and convex sides. In such a case, a second leaf similar in size and shape to the first leaf was chosen.

Cell length and width

A series of cells from the base to the tip of the leaf were measured for length. These measurements were divided into three parts. The first five were designated as basal cells, the last five as tip cells, and the centre five were centre cells. In small leaves, the parts of the leaf may overlap.

The first ten cells in this series were measured for width, at approximately one third from the base of the cell, unless this was where the cell curved. In this case, width was measured either above or below the curve. Width was measured on both the concave and convex sides of the leaf (or, on the convex (or concave) and middle for those species where the chlorophyllous cell is not extruded more on one side than the other such as in *S. wulfianum* and *S. magellanicum*).

C. PORE CHARACTERISTICS

Pore Size

Using the same series of cells as those measured for length, number of pores per cell and the size of individual pores was measured Pores were measured on both the concave and convex side of the leaf. Pore sizes were also broken down into the same designations - tip, centre and base - as the cell lengths. Pores that were not fully formed and did not appear to be perforations of the cell wall (pseudo-pores) were not counted.

Pore Frequency

The leaf was viewed with the 40X objective, and positioned so the eyepiece micrometer was along the length of the leaf (figure 4.2.1.2). The number of pores touching the striations of the eyepiece micrometer using a 40X objective was counted for both the concave and convex sides of the leaf at four locations (base, centre, tip and edge of the leaf).

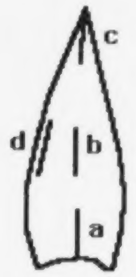


Figure 4.2.1.2. Approximate position of eyepiece micrometer with respect to leaf for pore and fibril frequency measurements on (a) base, (b) centre, (c) tip, and (d) edge of leaf.

Pore Area

Pore Area was determined using pore diameter to determine the area of an individual pore on the base, tip or centre of the leaf. Using mean pore size data, mean pore area for the base, tip, centre and edge of the leaf was determined. Pore area was multiplied with pore frequency to determine pore area. Pore area on the edge of the leaf was determined using the edge pore frequency data and the pore size data for the centre of the leaf, since edge pore size data were not available. Percent pore area on one side was determined by summing the pore area on the concave and convex sides of the leaf on the base, tip and centre, then determining the percentage share on each side.

D. FIBRIL CHARACTERISTICS

Fibril Frequency

The number of fibrils along the length of the eyepiece micrometer were counted for the base, centre, tip and edge of each leaf. This was done at the same location as pore frequency data was taken.

4.2.2 Statistical Analysis and Data Presentation

For each species, three individual sets of data were taken for leaf length, width, curvature; hyaline cell length and width; and pore size of the spreading branches, and one set of data for the hanging branches. The number of measurements taken in a species for a morphological characteristic is indicated by "n". In most cases, "n" is at least 15 (five measurements per individual plant.

For the leaf length, width, curvature; hyaline cell length and width; and pore size, data is presented in ascending order. Figures show the mean and standard deviation of all the values, as well as the mean and standard deviation for individual species. Subgeneric sections of *Sphagnum* are indicated by colours of bars, as in the absorbency data. Individual parts of the leaf, as well as average of all parts of the leaf are given for pore size data. A one-way ANOVA (using Microsoft Excel 4.0) was performed for each morphological characteristic for each species in order to determine if there were significant differences between the plants from which data were collected. The mean value and standard deviation for each characteristic are determined.

For pore and fibril frequency data, ten leaves from a single fascicle of each species were used. For each leaf, the fibril or pore frequency on the part of the leaf (base, centre, tip and edge) were counted. Data are presented in ascending order, as per the other morphological data. A one-way ANOVA was performed to determine if there are differences between species. Appendix 4 contains the Levene statistic (SPSS) and the Lilliefors statistic (SPSS) indicating whether the data has equal variance between the three samples and normal, respectively. In cases where the data set was either not normal, or has unequal variances, the ANOVA result was omitted. If there was insufficient data to determine normality or homogeneity of variance, the ANOVA result was also omitted.

Pore area and pore size data are combined to present pore area. Pore area is presented in three dimensional figures, showing the mean pore area for each leaf part.

4.3 Results of Spreading Branch Leaf Analyses

4.3.1 Leaf Size

Leaf size is not related to the subgeneric taxonomic sections of *Sphagnum* (figures 4.3.1.1 and 4.3.1.2). *Sphagnum cuspidatum* and *S. squarrosum* have the longest leaves, while *S. rubellum* and *S. fallax* have the shortest leaves. Members of Section *Sphagnum* all have leaves approximately equal in length and width.

Species in Section *Sphagnum* have the greatest leaf curvature (figure 4.3.1.3). *Sphagnum papillosum* has the greatest leaf curvature, followed by *S. imbricatum* and *S. magellanicum*. *Sphagnum cuspidatum* and *S. fallax* have the smallest leaf curvatures. Leaves of emergent *S. riparium* have a higher curvature (table 4.3.1.3), and are longer (table 4.3.1.1) and wider (table 4.3.1.2) than those of submerged *S. riparium*. Leaf shape is related to taxonomic group (figures 4.3.1.4, 4.3.1.5, 4.3.1.6 and 4.3.1.7). Leaves of Section *Sphagnum* have the largest width:length ratio, and have blunt-tipped leaves. All other groups have acute-tipped leaves.

Table 4.3.1.1 *Sphagnum* leaf length in millimeters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between leaf length of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	Mean (Std Dev) (mm)	n	F	P-value	F crit	sig. dif.
S. angustifolium	1.29 (0.12)	30		unequal variance		
S. cuspidatum	2.41 (0.73)	19	0.9494	0.3435	4.4513	
S. fallax	1.02 (0.07)	5		insufficient data		
S. fuscum	1.33 (0.28)	31	4.1082	0.0273	3.3404	*
S. girgensohnii	1.42 (0.23)	31		unequal variance		
S. imbricatum	1.79 (0.16)	21	3.7578	0.0433	3.5546	*
S. jensenii	2.01 (0.47)	20	7.3362	0.0050	3.5915	*
S. lindbergii	1.54 (0.35)	30	6.6578	0.0045	3.3541	*
S. magellanicum	1.78 (0.32)	19		data not normal		
S. majus	1.58 (0.22)	42	2.1925	0.1048	2.8517	
S. papillosum	1.60 (0.21)	26	3.5125	0.0466	3.4221	*
S. pulchrum	1.91 (0.36)	21	4.6918	0.0229	3.5546	*
S. riparium (emergent)	1.64 (0.21)	21		unequal variance		
S. riparium (submerged)	1.31 (0.10)	12		insufficient data		
S. rubellum	0.86 (0.07)	43	9.2546	0.0001	2.8451	*
S. squarrosum	2.08 (0.57)	20	3.0251	0.0991	4.4139	
S. wulfianum	1.34 (0.14)	30	0.2629	0.7707	3.3541	
ALL	**1.54 (0.48)**	**421**				

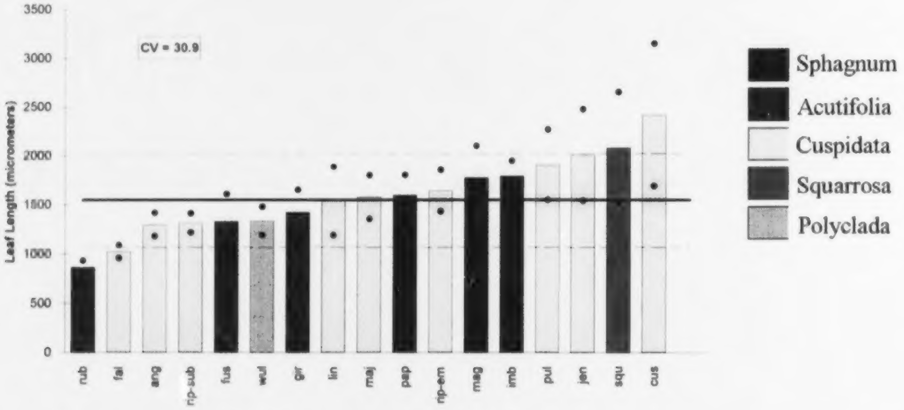


Figure 4.3.1.1. Leaf length of *Sphagnum* (μm). Centre line is mean of all species; upper and lower lines are one standard deviation from mean. Closed circles are one standard deviation from mean for individual species. CV = Variation Coefficient. Species are indicated by first three letters of specific epithet, as per table 4.3.1.1.

Table 4.3.1.2. *Sphagnum* leaf width in millimeters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between leaf width of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	0.35 (0.03)	3	insufficient data			
S. cuspidatum	0.54 (0)	1	insufficient data			
S. fallax	0.35 (0)	1	insufficient data			
S. fuscum	0.40 (0.05)	21	2.7619	0.0899	3.5546	
S. girgensohnii	0.48 (0.08)	21	3.8467	0.0406	3.5546	*
S. imbricatum	0.82 (0.04)	3	insufficient data			
S. jensenii	0.56 (0.16)	10	8.8042	0.0179	5.3176	*
S. lindbergii	0.46 (0.09)	20	0.1523	0.7009	4.4139	
S. magellanicum	0.78 (0.09)	13	0.1500	0.8625	3.9823	
S. majus	0.45 (0.12)	22	2.6385	0.0809	3.1599	
S. papillosum	0.95 (0.17)	21	0.0007	0.9786	4.4139	
S. pulchrum	0.57 (0.13)	21	2.9887	0.0757	3.5546	
S. riparium (emergent)	0.59 (0.06)	3	insufficient data			
S. riparium (submerged)	0.34 (0)	1	insufficient data			
S. rubellum	0.30 (0.04)	13	insufficient data			
S. squarrosum	1.06 (0.19)	11	insufficient data			
S. wulfianum	0.41 (0.04)	20	0.1116	0.7422	4.4139	
ALL	**0.56 (0.24)**	**205**				

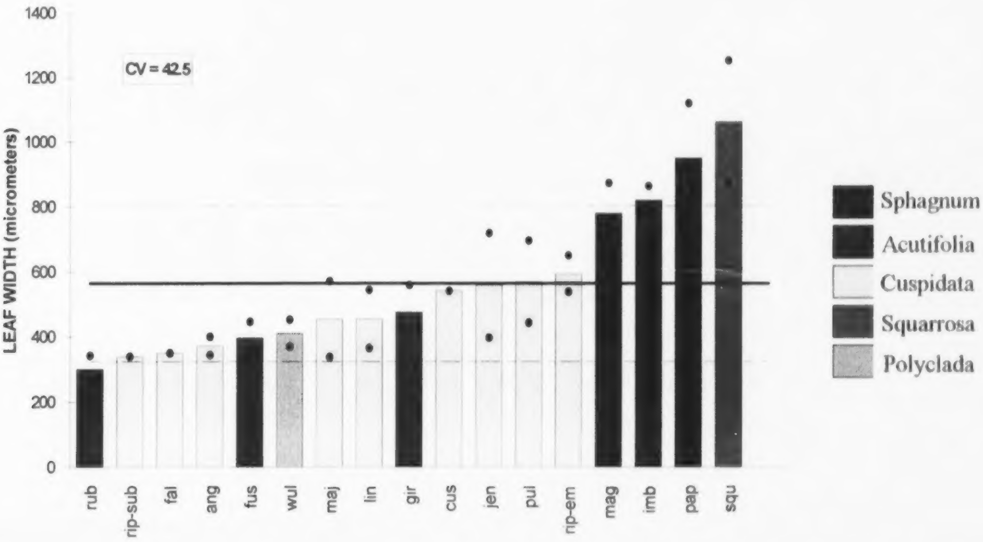


Figure 4.3.1.2. Leaf width of *Sphagnum*. Centre line is mean of all species; upper and lower lines are one standard deviation from mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient. Species are indicated by first three letters of specific epithet, as per table 4.3.1.2.

Table 4.3.1.3. *Sphagnum* leaf curvature (µm). "n" is the number of measurements made. Asterisk (*) indicates significant difference between leaf curvature of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**@ 0.05 df**
S. angustifolium	171.05 (23.06)	30	25.3701	$6.3x10^{-7}$	3.3541	*
S. cuspidatum	111.64 (32.62)	17	data not normal			
S. fallax	113.87 (29.92)	5	insufficient data			
S. fuscum	96.67 (12.88)	21	6.5316	0.0193	4.3808	*
S. girgensohnii	174.45 (39.26)	20	2.4009	0.1207	3.5915	
S. imbricatum	495.62 (104.57)	20	25.7147	$7.2x10^{-6}$	3.5915	*
S. jensenii	203.89 (90.11)	12	insufficient data			
S. lindbergii	182.68 (32.95)	15	0.6226	0.5530	3.8853	
S. magellanicum	417.97 (155.90)	13	insufficient data			
S. majus	156.65 (32.50)	33	9.8545	0.0001	2.9340	*
S. papillosum	693.43 (154.84)	2	insufficient data			
S. pulchrum	215.73 (38.47)	9	insufficient data			
S. riparium (emergent)	264.57 (30.01)	22	4.7145	0.0421	4.3513	*
S. riparium (submerged)	165.89 (13.88)	11	insufficient data			
S. rubellum	168.65 (31.00)	38	unequal variances			
S. squarrosum	277.37 (15.99)	6	insufficient data			
S. wulfianum	154.33 (19.07)	21	data not normal			
ALL	**210.31 (118.54)**	**295**				

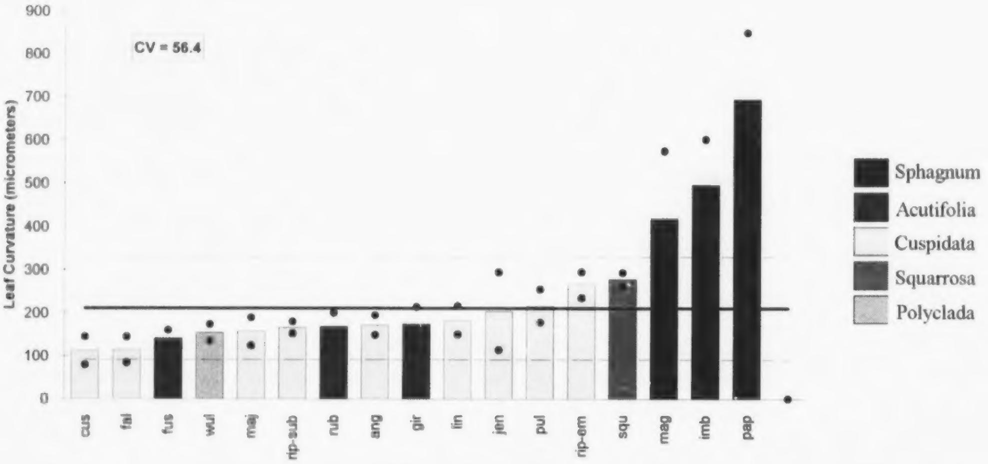
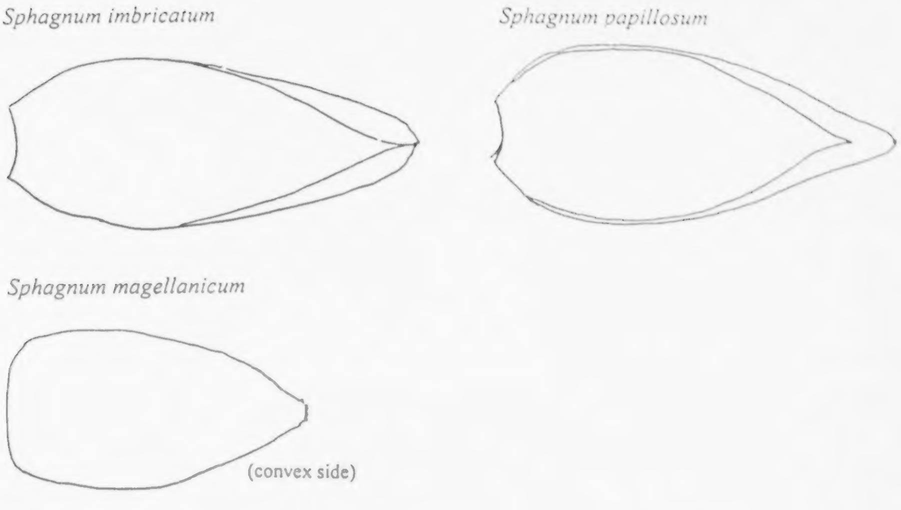


Figure 4.3.1.3: Leaf curvature of *Sphagnum* (µm). Centre line is mean of all species; upper and lower lines are one standard deviation from mean. Closed circles are one standard deviation from mean for individual species. CV = Variation Coefficient. Species are indicated by first three letters of specific epithet, as per table 4.3.1.3.

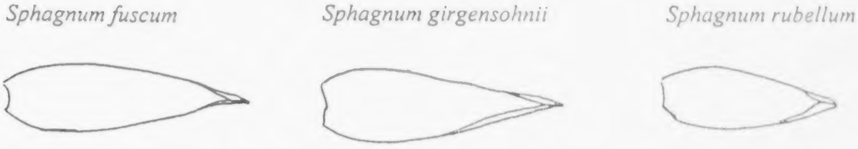


Sphagnum imbricatum

Sphagnum papillosum

Sphagnum magellanicum

Figure 4.3.1.4: A representative leaf from one of the plants from which data were measured in species of Section *Sphagnum*.

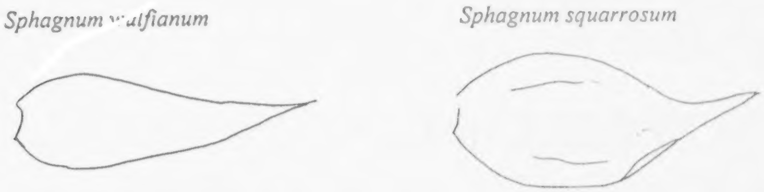


Sphagnum fuscum

Sphagnum girgensohnii

Sphagnum rubellum

Figure 4.3.1.5: A representative leaf from one of the plants from which data were measured in species of Section *Acutifolia*.

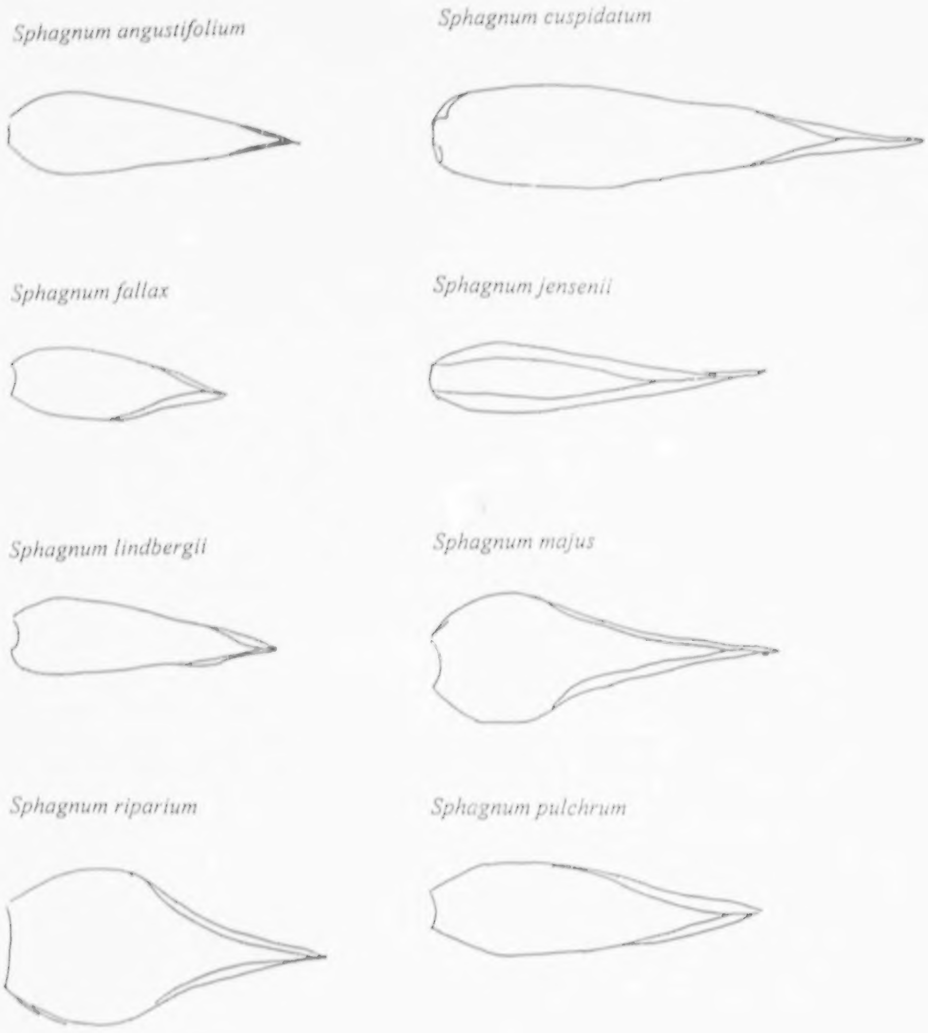


Sphagnum wulfianum

Sphagnum squarrosum

Figure 4.3.1.6: A representative leaf from one of the plants from which data were measured in species of Sections *Polyclada* (left) and *Squarrosa* (right).

1 mm



Sphagnum angustifolium

Sphagnum cuspidatum

Sphagnum fallax

Sphagnum jensenii

Sphagnum lindbergii

Sphagnum majus

Sphagnum riparium

Sphagnum pulchrum

Figure 4.3.1.7: A representative leaf from one of the plants from which data were measured in species of Section *Cuspidata*.

1 mm

4.3.2 Hyaline Cell Size

Hyaline cells of the sixteen species sampled ranged from less than 50 µm (*Sphagnum rubellum* tip cells, figure 4.3.2.3) to basal cells of *S. squarrosum*, which can be over 200 µm in length (figure 4.3.2.1). Cell length is not related to subgeneric divisions in *Sphagnum*. The five species with the longest cells and the five species with the shortest cells both contain at least one member of the three major taxonomic groups (figure 4.3.2.4).

There is a significant difference between the mean cell lengths of the three individual plants of *S. magellanicum* and *S. cuspidatum* (table 4.3.2.4). Basal and tip hyaline cell lengths are more consistent between individuals of a population than are middle cells (tables 4.3.2.1, 4.3.2.2, and 4.3.2.3). This is because the transition from long basal cells to short tip cells did not always occur at the same place in different species, thus "middle" cells may be long like basal cells, short like tip cells or may contain both cell types. The larger variation of the middle cells reflects this (figure 4.3.2.2).

Cell widths range from 12 µm in *S. wulfianum* to over 30 µm in *S. papillosum*, *S. imbricatum* and *S. squarrosum* (table 4.3.2.5). Cell width is related to subgeneric sections. Species in Section *Sphagnum*, and *S. squarrosum* have the widest cells (figure 4.3.2.5). Species in Section *Acutifolia* have wider cells than species in Section *Cuspidata* (with *S. rubellum* being the exception). *Sphagnum wulfianum* has the thinnest cells out of all the species measured. Cell widths are not consistent in half of the species measured. In species of Sections *Acutifolia* and *Sphagnum*, the cells are wide and irregularly shaped, while cell widths are more uniform in the other groups. The variation in the cell widths of species in Sections *Acutifolia* and *Sphagnum* reflects this .

Table 4.3.2.1. Basal hyaline cell length (micrometers). First five hyaline cells measured, beginning from base of leaf. "n" is the number of measurements made. Asterisk (*) indicates significant difference between basal hyaline cell length of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	122.99 (17.58)	15	6.9667	0.0098	3.8853	*
S. cuspidatum	167.79 (70.79)	10	8.2719	0.0206	5.3176	*
S. fallax	87.36 (15.81)	5	insufficient data			
S. fuscum	156.38 (41.59)	15	13.4640	0.0001	3.2849	*
S. girgensohnii	149.38 (29.03)	15	4.3859	0.0372	3.8853	*
S. imbricatum	178.16 (33.08)	15	2.7736	0.1023	3.8853	
S. jensenii	149.38 (19.67)	15	2.8218	0.0990	3.8853	
S. lindbergii	140.14 (25.34)	15	4.0005	0.0466	3.8853	*
S. magellanicum	104.51 (20.19)	15	9.3765	0.0035	3.8853	*
S. majus	153.14 (31.90)	20	0.2620	0.8517	3.2389	
S. papillosum	152.25 (15.26)	10	unequal variances			
S. pulchrum	161.35 (36.19)	15	2.1854	0.1551	3.8853	
S. riparium - emergent	144.48 (21.70)	10	0.0008	0.9777	5.3176	
S. riparium - submerged	129.36 (32.81)	5	insufficient data			
S. rubellum	89.83 (19.80)	20	12.5546	0.0002	3.2389	*
S. squarrosum	181.44 (62.68)	10	6.3051	0.0363	5.3176	*
S. wulfianum	138.95 (26.13)	15	3.5695	0.0608	3.8853	
ALL	**140.88 (41.35)**	**225**				

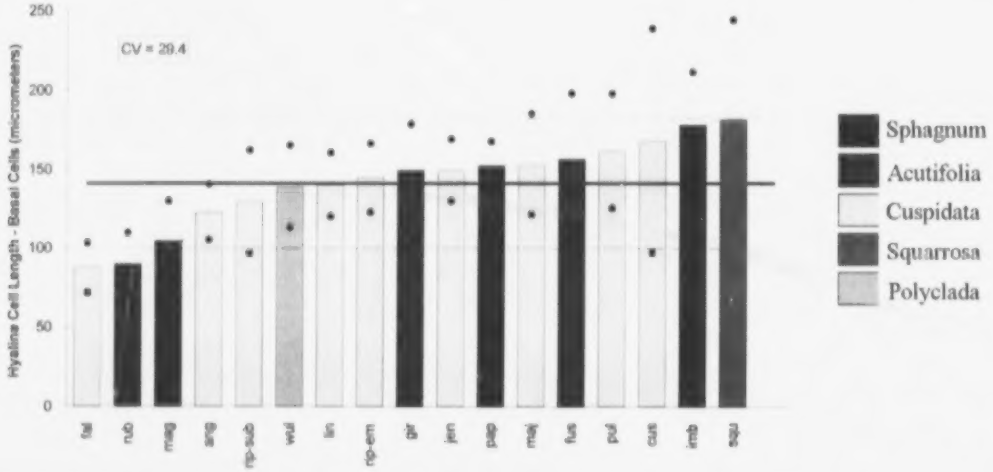


Figure 4.3.2.1. Basal hyaline cell lengths of *Sphagnum* (μm). Species are indicated by first three letters of specific epithet, as listed in table 4.3.2.1. Centre line is mean of all species, upper and lower lines are one standard deviation. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient

Table 4.3.2.2. Hyaline cell lengths in center of leaf (micrometers). Centre five hyaline cells measured in each leaf. "n" is the number of measurements made. Asterisk (*) indicates significant difference between centre hyaline cell length of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	Mean (Std Dev)	n	F	P-value	F crit	sig. dif.
S. angustifolium	103.04 (19.61)	15	2.3610	0.1366	3.8853	
S. cuspidatum	147.84 (50.06)	10	30.0855	0.0006	5.3176	*
S. fallax	59.43 (13.50)	5	insufficient data			
S. fuscum	143.01 (33.80)	15	9.7769	0.0030	3.8853	*
S. girgensohnii	109.55 (27.45)	15	9.8365	0.0030	3.8853	*
S. imbricatum	114.76 (19.81)	15	7.2225	0.0087	3.8853	*
S. jensenii	135.24 (20.86)	15	5.1409	0.0244	3.8853	*
S. lindbergii	107.03 (30.18)	15	data not normal / unequal variances			
S. magellanicum	101.08 (22.40)	15	16.3576	0.0004	3.8853	*
S. majus	131.99 (19.57)	20	unequal variances			
S. papillosum	133.04 (27.44)	10	52.5724	0.0001	5.3176	*
S. pulchrum	128.03 (29.50)	15	data not normal			*
S. riparium - emergent	83.58 (15.89)	10	18.5687	0.0026	5.3176	*
S. riparium - submerged	87.15 (6.64)	5	insufficient data			
S. rubellum	68.99 (15.12)	20	2.2624	0.1204	3.2389	
S. squarrosum	104.79 (26.44)	10	6.8140	0.0311	5.3176	*
S. wulfianum	72.66 (12.72)	15	3.1253	0.0808	3.8853	
ALL	**110.56 (34.70)**	**225**				

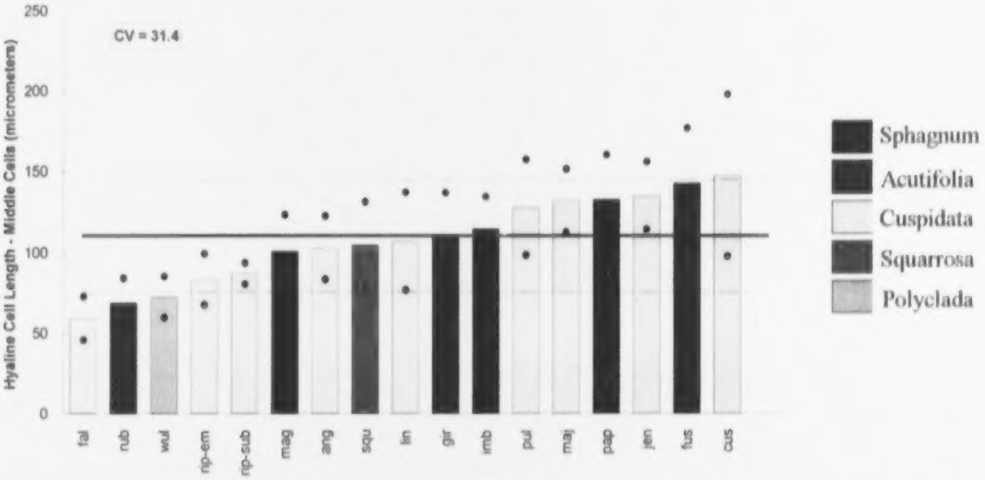


Figure 4.3.2.2. Centre hyaline cell lengths of *Sphagnum* (μm). Species are indicated by first three letters of specific epithet, as listed in table 4.3.2.2. Centre line is mean of all species, upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient.

Table 4.3.2.3. Tip hyaline cell lengths (micrometers). Uppermost five hyaline cells measured in each leaf. "n" is the number of measurements made. Asterisk (*) indicates significant difference between tip hyaline cell length of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	60.69 (9.10)	15	data not normal			
S. cuspidatum	72.98 (8.23)	10	0.4416	0.5251	5.3176	
S. fallax	55.44 (22.61)	5	insufficient data			
S. fuscum	109.48 (28.28)	15	15.3692	0.0005	3.8853	*
S. girgensohnii	76.23 (14.86)	15	1.8121	0.2053	3.8853	
S. imbricatum	73.88 (23.42)	15	3.4673	0.0648	3.8853	
S. jensenii	108.64 (16.01)	15	0.4919	0.6233	3.8853	
S. lindbergii	81.27 (15.76)	15	4.5003	0.0348	3.8853	*
S. magellanicum	75.95 (22.13)	15	unequal variances / data not normal			
S. majus	116.87 (17.53)	20	9.3563	0.0008	3.2389	*
S. papillosum	109.52 (33.86)	10	unequal variances			
S. pulchrum	92.61 (16.66)	15	3.5117	0.0630	3.8853	
S. riparium-emergent	51.24 (8.53)	10	1.2174	0.3020	5.3176	
S. riparium-submerged	80.64 (6.19)	5	insufficient data			
S. rubellum	48.51 (10.06)	20	data not normal			
S. squarrosum	61.01 (12.82)	10	9.3467	0.0156	5.3176	*
S. wulfianum	56.14 (9.28)	15	6.4855	0.0123	3.8853	*
ALL	**79.82 (28.28)**	**225**				

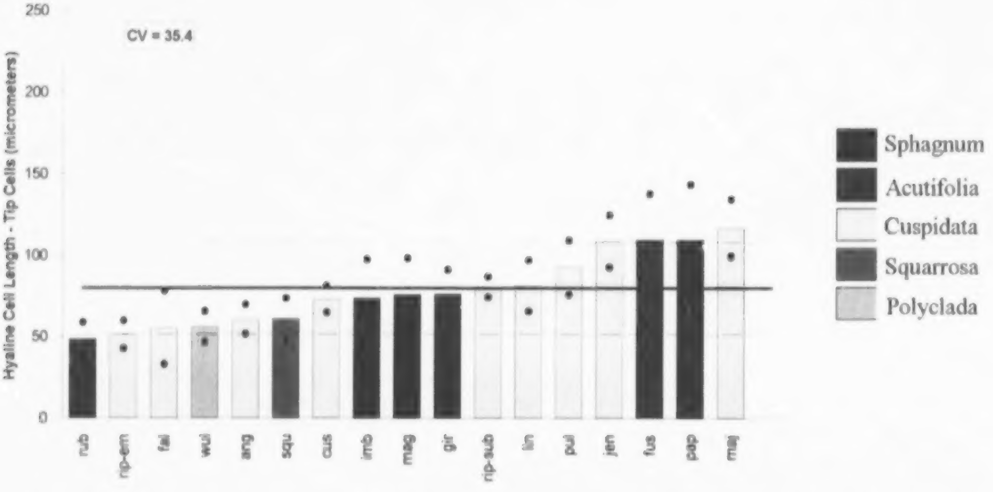


Figure 4.3.2.3. Tip hyaline cell lengths of *Sphagnum* (μm). Species are indicated by first three letters of specific epithet, as listed in table 4.3.2.3. Centre line is mean of all species, upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient

Table 4.3.2.4. Mean of all hyaline cell lengths (micrometers). "n" is the number of measurements made. Asterisk (*) indicates significant difference between mean hyaline cell lengths of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	Mean (Std Dev)	n	F	P-value	F crit	sig. dif.
S. angustifolium	88.34 (29.02)	52	2.0153	0.1442	3.1866	
S. cuspidatum	122.72 (59.49)	40	data not normal			
S. fallax	69.68 (24.32)	11	insufficient data			
S. fuscum	133.06 (40.93)	36	0.3463	0.7097	3.2594	
S. girgensohnii	112.28 (39.08)	43	2.2525	0.1183	3.2317	
S. imbricatum	121.37 (50.64)	46	data not normal			
S. jensenii	132.47 (25.42)	43	4.0836	0.0243	3.2317	*
S. lindbergii	106.86 (33.86)	39	0.1827	0.8337	3.2381	
S. magellanicum	91.45 (23.62)	53	22.1473	$1.3x10^{-7}$	3.1826	*
S. majus	134.70 (27.45)	66	0.5518	0.6489	2.7608	
S. papillosum	125.57 (30.68)	27	data not normal / unequal variances			
S. pulchrum	128.31 (38.42)	54	1.5295	0.2268	3.1866	
S. riparium-emergent	91.61 (38.46)	40	0.6160	0.4374	4.0982	
S. riparium-submerged	99.38 (29.89)	10	insufficient data			
S. rubellum	67.85 (22.59)	61	4.1775	0.0096	2.7664	*
S. squarrosum	114.04 (57.32)	41	7.0813	0.0113	4.0913	*
S. wulfianum	89.29 (40.68)	49	data not normal / unequal variances			
ALL	**111.17 (42.99)**	**751**				

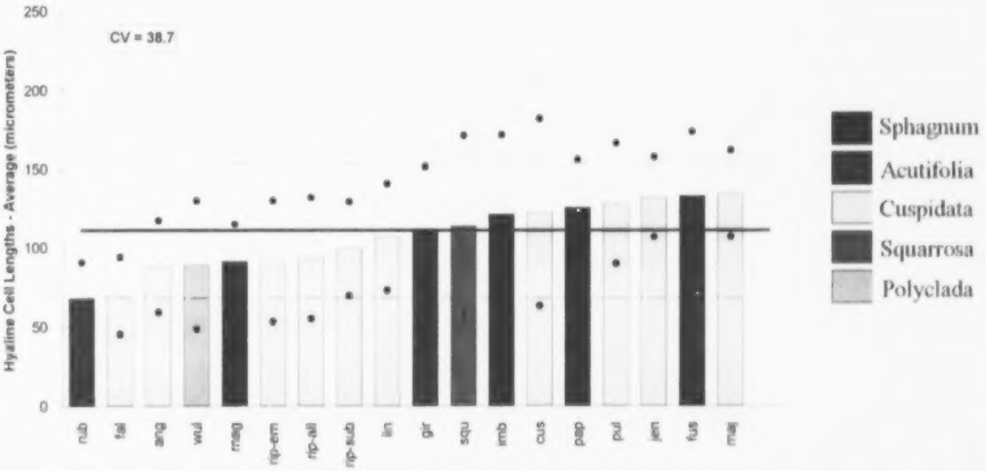


Figure 4.3.2.4. Mean of all hyaline cell lengths of *Sphagnum*. Species are indicated by first three letters of specific epithet, as listed in table 4.3.2.4. Centre line is mean of all species, upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient

Table 4.3.2.5. Hyaline cell widths (micrometers) of first 10 cells in leaf (starting from base). "n" is the number of measurements made. Asterisk (*) indicates significant difference between hyaline cell width of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	Mean (Std Dev)	n	F	P-value	F crit	sig. dif.
S. angustifolium	17.29 (2.86)	30	0.3382	0.7160	3.3541	
S. cuspidatum	15.80 (2.58)	20	data not normal			
S. fallax	15.12 (2.51)	10	insufficient data			
S. fuscum	20.06 (5.37)	30	15.7725	$2.9x10^{-5}$	3.3541	*
S. girgensohnii	21.70 (4.79)	30	25.7830	$5.5x10^{-7}$	3.3541	*
S. imbricatum	26.72 (5.48)	30	data not normal			
S. jensenii	14.28 (2.04)	30	2.1830	0.1322	3.3541	
S. lindbergii	15.82 (2.35)	30	3.9885	0.0304	3.3541	*
S. magellanicum	23.42 (4.55)	30	15.8804	$2.8x10^{-5}$	3.3541	*
S. majus	15.57 (3.16)	40	7.3761	0.0006	2.8663	*
S. papillosum	26.99 (4.82)	20	data not normal / unequal variances			
S. pulchrum	18.61 (3.33)	29	7.8828	0.0021	3.3690	*
S. riparium (emergent)	17.22 (3.00)	20	5.0281	0.0378	4.4139	*
S. riparium (submerged)	13.97 (1.92)	10	insufficient data			
S. rubellum	14.15 (3.38)	40	29.8266	$7.2x10^{-10}$	2.8663	*
S. squarrosum	26.49 (6.74)	20	0.9131	0.3520	4.4139	
S. wulfianum	13.20 (1.37)	30	data not normal / unequal variances			
ALL	**18.54 (5.88)**	**449**				

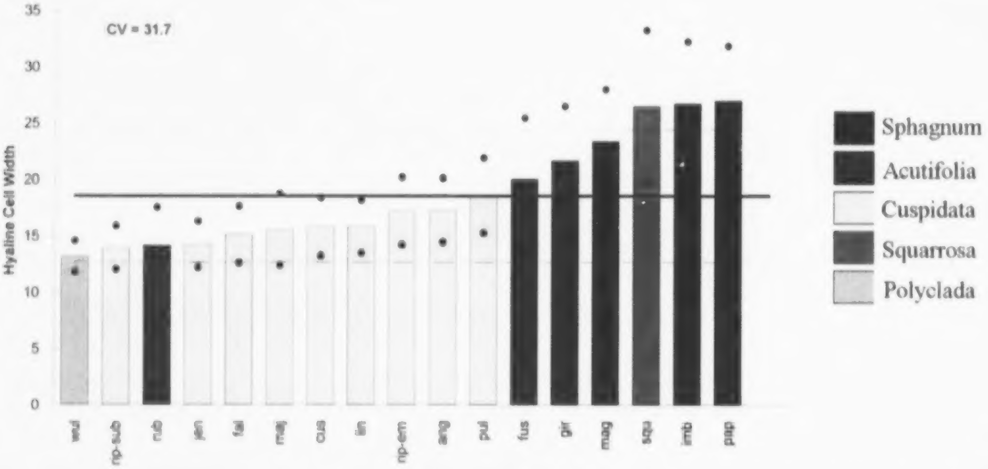


Figure 4.3.2.5. Hyaline cell widths. Species are indicated by first three letters of specific epithet, as listed in table 4.3.2.5. Centre line is mean of all species, upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient

4.3.3 Pores

Pore Diameter

In the sixteen species of *Sphagnum* studied, pores ranged in size from less than 3 µm (*S. pulchrum* convex basal cells, figure 4.3.3.2) to more than 25 µm (*S. fuscum*, concave basal cells, figure 4.3.3.1). Pore sizes are related to subgeneric sections of *Sphagnum* (figures 4.3.3.1 and 4.3.3.2). Pores of species in Sections *Cuspidata* and *Polyclada* are less than 10 µm. With the exception of *S. rubellum*, in which most pores are less than 10 µm, pores in species of Sections *Acutifolia*, *Squarrosa* and *Sphagnum* have pores greater than 10 µm. Pores of species in Sections *Acutifolia*, *Sphagnum* and *Squarrosa* range between 12 µm and 20 µm. Mean pore sizes in these three groups are similar (figure 4.3.3.4).

There is a tendency for concave pores to be smaller near the tip and larger near the base. In the cases of *S. squarrosum* and *S. fuscum*, this is a substantial difference (greater than 100% for *S. fuscum*, figure 4.3.3.1). This tendency is also present on the convex side of the leaf (figure 4.3.3.2). When comparing the concave and the convex side of the same portion of the leaf, pores are approximately equal in size for most species.

For most species, there are insufficient pore data to run ANOVA analyses to determine significant differences among the three individuals within a species (tables 4.3.3.1 to 4.3.3.8). Much of the data is not normal when considering pore diameters on all parts of the leaf (tables 4.3.3.7 and 4.3.3.8), and thus ANOVA analyses could not be run for most species. In those species for which ANOVA analyses were performed, only *S. papillosum* did not demonstrate a significant difference in concave or convex mean pore size between the three individuals within the population (tables 4.3.3.7 and 4.3.3.8). In those species with no pores in a particular leaf area in all three individuals (e.g., *S. majus* on the concave side of the leaf), we can assume there is no significant difference for that character within the population even though an analysis of variance could not be performed.

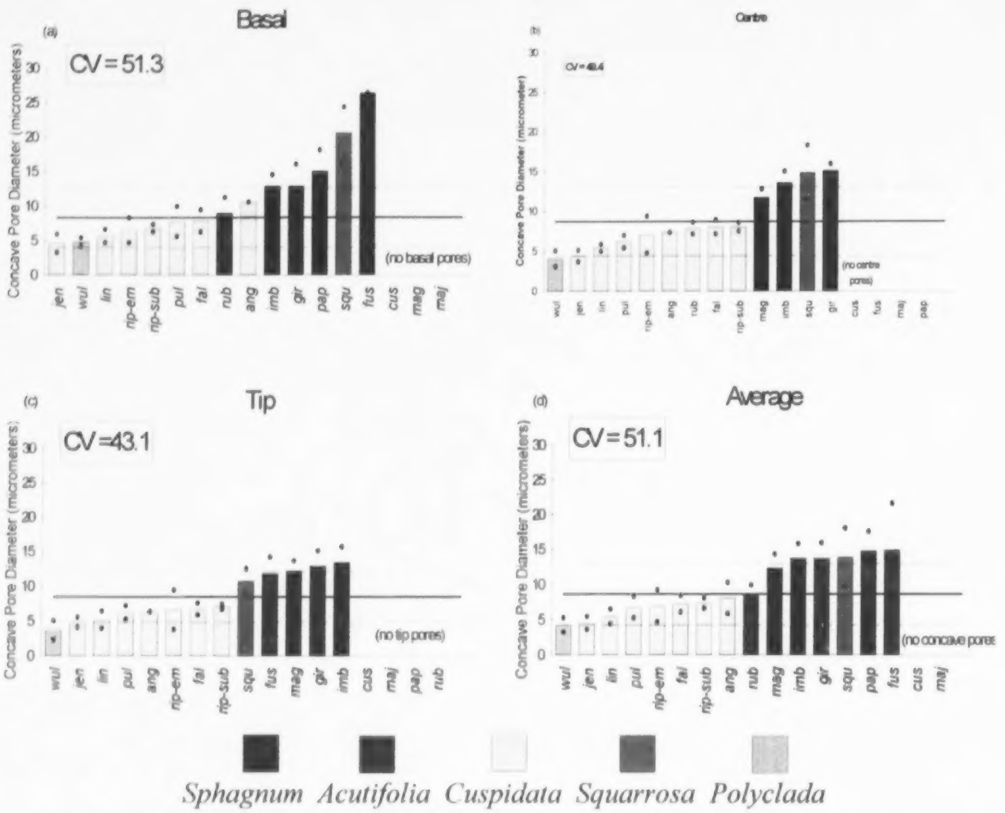


Figure 4.3.3.1: Concave pore size (µm) on (a) basal (b) centre (c) tip and (d) mean of all parts of the leaf. Species are indicated by first three letters of specific epithet as listed in tables 4.3.3.3 to 4.3.3.10. Centre line is mean of all species. Upper and lower lines are one standard deviation from mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient.

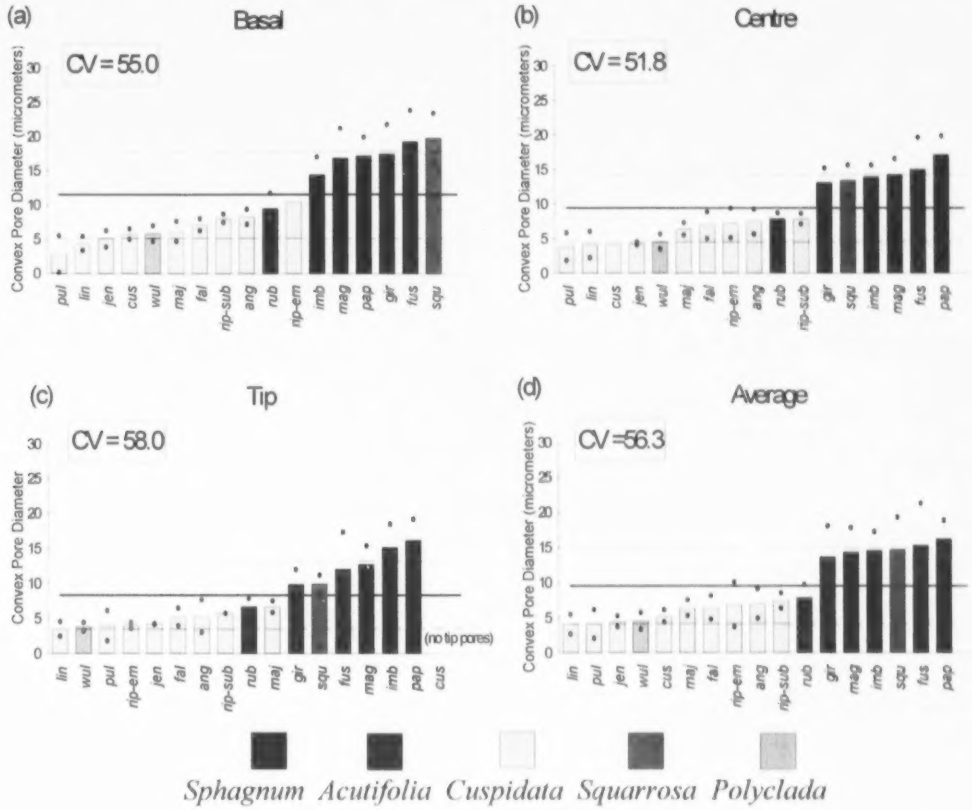


Figure 4.3.3.2: Convex pore size (μm) on (a) basal (b) centre (c) tip and (d) mean of all parts of the leaf. Species are indicated by first three letters of specific epithet as listed in tables 4.3.3.3 to 4.3.3.10. Centre line is mean of all species. Upper and lower lines are one standard deviation from mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient.

Table 4.3.3.1: Concave basal pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between concave basal pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F Crit**	**sig. dif.**
S. angustifolium	10.50 (0)	1		insufficient data		
S. cuspidatum		0		no pores		
S. fallax	7.81 (1.58)	3		insufficient data		
S. fuscum	26.25 (0)	2		insufficient data		
S. girgensohnii	12.78 (3.16)	3		insufficient data		
S. imbricatum	12.77 (1.65)	4		insufficient data		
S. jensenii	4.57 (1.32)	14		data not normal		
S. lindbergii	5.61 (0.96)	14	1.0413	0.3854	3.9823	
S. magellanicum		0		no pores		
S. majus		0		no pores		
S. papillosum	14.97 (3.03)	5		insufficient data		
S. pulchrum	7.71 (2.17)	15		data not normal		
S. riparium (emergent)	6.46 (1.78)	10		data not normal		
S. riparium (submerged)	6.77 (0.55)	4		insufficient data		
S. rubellum	8.93 (2.23)	2		insufficient data		
S. squarrosum	20.48 (3.71)	2		insufficient data		
S. wulfianum	4.76 (0.60)	8		insufficient data		
ALL	**8.24 (4.23)**	**86**				

Table 4.3.3.2: Concave centre pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between concave centre pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F Crit**	**sig. dif.**
S. angustifolium	7.35 (0)	1		insufficient data		
S. cuspidatum		0		no pores		
S. fallax	8.02 (0.89)	5		insufficient data		
S. fuscum		0		no pores		
S. girgensohnii	15.10 (0.80)	9		insufficient data		
S. imbricatum	13.54 (1.46)	9		insufficient data		
S. jensenii	4.39 (0.70)	14		data not normal		
S. lindbergii	5.43 (0.45)	10	4.1123	0.0659	4.7374	
S. magellanicum	11.73 (1.03)	6		insufficient data		
S. majus		0		no pores		
S. papillosum		0		no pores		
S. pulchrum	6.20 (0.77)	15	27.4824	$3.3\text{x}10^{-5}$	3.8853	*
S. riparium (emergent)	7.08 (2.31)	10	118.2725	$4.5\text{x}10^{-5}$	5.3176	*
S. riparium (submerged)	8.02 (0.52)	5		insufficient data		
S. rubellum	7.88 (0.74)	2		insufficient data		
S. squarrosum	14.82 (3.45)	9	7.5037	0.0289	5.5915	*
S. wulfianum	4.05 (0.99)	7		insufficient data		
ALL	**8.73 (4.31)**	**102**				

Table 4.3.3.3: Concave tip pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between concave tip pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F Crit**	**sig. dif.**
S. angustifolium	6.30 (0)	1		insufficient data		
S. cuspidatum		0		no pores		
S. fallax	6.72 (0.86	5		insufficient data		
S. fuscum	11.81 (2.34)	6		insufficient data		
S. girgensohnii	12.89 (2.17)	15	0.4600	0.6419	3.8853	
S. imbricatum	13.43 (2.24)	4		insufficient data		
S. jensenii	4.80 (0.73)	7		insufficient data		
S. lindbergii	5.17 (1.22)	14	8.1671	0.0067	3.9823	*
S. magellanicum	12.20 (1.41)	7		insufficient data		
S. majus		0		no pores		
S. papillosum		0		no pores		
S. pulchrum	6.22 (0.98)	15		data not normal		
S. riparium (emergent)	6.58 (2.81)	10	107.7648	6.4x10^{-6}	5.3176	*
S. riparium (submerged)	7.04 90.360	5		insufficient data		
S. rubellum		0		no pores		
S. squarrosum	10.74 (1.75)	10		data not normal		
S. wulfianum	3.68 (1.36)	4		insufficient data		
ALL	**8.42 (3.63)**	**102**				

Table 4.3.3.4: Mean of concave pore diameters from all parts of the leaf. "n" is the number of measurements made. Asterisk (*) indicates significant difference betweenconcave pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F Crit**	**sig. dif.**
S. angustifolium	8.05 (2.19)	4		insufficient data		
S. cuspidatum		0		no pores		
S. fallax	7.23 (1.17)	9		insufficient data		
S. fuscum	14.88 (6.72)	9		insufficient data		
S. girgensohnii	13.70 (2.23)	27	4.0252	0.0311	3.4028	*
S. imbricatum	13.67 (2.08)	16	4.2997	0.0369	3.8056	*
S. jensenii	4.51 (0.94)	39	1.6020	0.2155	3.2594	
S. lindbergii	5.43 (1.03)	35	3.3874	0.0463	3.2945	*
S. magellanicum	12.29 (2.00)	19	0.9704	0.4001	3.6337	
S. majus		0		no pores		
S. papillosum	14.75 (2.77)	6	0.1587	0.7107	7.7086	
S. pulchrum	6.75 (1.51)	53	5.5865	0.0065	3.1826	*
S. riparium (emergent)	6.89 (2.27)	31	121.5306	6.9x10^{-12}	4.1830	*
S. riparium (submerged)	7.33 (0.74)	13		insufficient data		
S. rubellum	8.40 (1.48)	4		insufficient data		
S. squarrosum	13.87 (4.13)	29	11.4091	0.0022	4.2100	*
S. wulfianum	4.22 99.96)	20	1.9143	0.1779	3.5915	
ALL	**8.58 (4.39)**	**314**				

Table 4.3.3.5: Basal convex pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between convex basal pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	8.25 (1.10)	13	insufficient data			
S. cuspidatum	5.78 (0.74)	2	insufficient data			
S. fallax	7.14 (0.88)	5	insufficient data			
S. fuscum	19.24 (4.55)	14	1.2643	0.3205	3.9823	
S. girgensohnii	17.47 (4.21)	15	0.1997	0.8217	3.8853	
S. imbricatum	14.40 (2.57)	15	1.8908	0.1969	3.9823	
S. jensenii	5.08 (1.19)	15	data not normal			
S. lindbergii	4.38 (1.03)	6	13.0000	0.0333	9.5521	*
S. magellanicum	16.83 (4.29)	15	0.5845	0.5725	3.8853	
S. majus	6.16 (1.47)	19	insufficient data			
S. papillosum	17.17 (2.71)	15	0.3056	0.7422	3.8853	
S. pulchrum	2.84 (2.69)	15	insufficient data			
S. riparium (emergent)	10.50 (0)	1	insufficient data			
S. riparium (submerged)	8.05 (0.61)	3	insufficient data			
S. rubellum	9.51 (2.21)	16	insufficient data			
S. squarrosum	19.78 (3.59)	9	10.8754	0.0132	5.5915	*
S. wulfianum	5.86 (1.13)	10	insufficient data			
ALL	**11.50 (6.32)**	**188**				

Table 4.3.3.6: Centre convex pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between centre convex pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	7.44 (1.82)	12	insufficient data			
S. cuspidatum	4.20	1	insufficient data			
S. fallax	6.93 (1.91)	5	insufficient data			
S. fuscum	15.05 (4.60)	15	8.4787	0.0051	3.8853	*
S. girgensohnii	13.15 (2.05)	15	6.4188	0.0127	3.8853	*
S. imbricatum	13.96 (1.65)	15	4.4616	0.0356	3.8853	*
S. jensenii	4.28 (0.23)	15	data not normal / unequal variances			
S. lindbergii	4.14 (1.89)	13	3.2576	0.0814	4.1028	
S. magellanicum	14.29 (2.26)	15	2.8419	0.0976	3.8853	
S. majus	6.42 (0.91)	20	11.1856	0.0003	3.2389	*
S. papillosum	17.17 (2.71)	15	0.3056	0.7422	3.8853	
S. pulchrum	3.82 (1.99)	15	data not normal			
S. riparium (emergent)	7.25 (2.12)	7	insufficient data			
S. riparium (submerged)	7.88 (0.74)	2	insufficient data			
S. rubellum	7.87 (0.87)	20	3.0045	0.0613	3.2389	
S. squarrosum	13.45 (2.18)	9	unequal variances			
S. wulfianum	4.56 (1.08)	15	unequal variances			
ALL	**9.41 (4.88)**	**209**				

Table 4.3.3.7: Tip convex pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between tip convex pore diameters of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**sig. dif.**
S. angustifolium	5.40 (2.33)	13	insufficient data			
S. cuspidatum	0 (0)	0	no pores			
S. fallax	5.25 (1.29)	5	insufficient data			
S. fuscum	12.08 (5.31)	15	66.1171	3.3×10^{-7}	3.8853	*
S. girgensohnii	9.91 (2.10)	15	unequal variances / data not normal			
S. imbricatum	15.17 (3.28)	11	2.4856	0.1286	3.9823	
S. jensenii	4.22 (0.06)	15	data not normal			
S. lindbergii	3.53 (1.05)	14	6.9600	0.0111	3.9823	*
S. magellanicum	12.75 (2.62)	15	9.5654	0.0033	3.8853	*
S. majus	6.74 (0.84)	20	4.7624	0.0147	3.2389	*
S. papillosum	16.21 (2.99)	15	unequal variances / data not normal			
S. pulchrum	4.00 (2.13)	15	data not normal			
S. riparium (emergent)	4.05 (0.40)	5	insufficient data			
S. riparium (submerged)	5.78 (0)	1	insufficient data			
S. rubellum	6.72 (1.17)	20	3.9865	0.0269	3.2389	*
S. squarrosum	9.98 (1.25)	8	insufficient data			
S. wulfianum	3.84 (0.62)	15	7.1382	0.0091	3.8853	*
ALL	**8.35 (4.85)**	**202**				

Table 4.3.3.8: Mean of all convex pore diameters. "n" is the number of measurements made. Asterisk (*) indicates significant difference between convex pore diameter of the three individuals within a species determined using an ANOVA (alpha = 0.05).

Species	**Mean (Std Dev)**	**n**	**F**	**P-value**	**F crit**	**@ 0.05 df**
S. angustifolium	7.02 2.10	43	unequal variances			
S. cuspidatum	5.25 0.86	4	insufficient data			
S. fallax	6.49 1.68	11	insufficient data			
S. fuscum	15.33 5.97	31	data not normal			
S. girgensohnii	13.65 4.40	41	data not normal			
S. imbricatum	14.59 2.65	40	data not normal			
S. jensenii	4.49 0.75	50	data not normal			
S. lindbergii	4.09 1.38	27	5.5430	0.0105	3.4028	*
S. magellanicum	14.36 3.41	53	data not normal			
S. majus	6.45 1.11	62	data not normal			
S. papillosum	16.24 2.60	46	1.9451	0.1553	3.2145	
S. pulchrum	4.12 2.03	39	data not normal			
S. riparium (emergent)	6.89 3.18	17	data not normal			
S. riparium (submerged)	7.46 1.08	5	insufficient data			
S. rubellum	7.89 1.83	57	data not normal			
S. squarrosum	14.65 4.67	33	4.3076	0.0463	4.1596	*
S. wulfianum	4.60 1.18	39	data not normal			
ALL	**0.010 0.005**	**598**				

Pore Frequencies

The basal portions of leaves have the fewest pores, and the tips of the leaves have the highest mean pore frequency (figures 4.3.3.3 and 4.3.3.4). Pore frequency on the edge of the leaf is similar on both the concave and convex sides. For all groups and species, the edges of the leaf have the least amount of variation.

Most of the pores of species in Section *Cuspidata* are on the concave side of the leaf. *Sphagnum majus* is the exception to this (figures 4.3.3.3 and 4.3.3.4). Only *S. majus* had an occasional pore on the concave side of the leaf (in the three leaves sampled, a total of three concave pores were found).

Species in Section *Sphagnum* have almost all of their pores on the convex surface of the leaf. The exception to this is the edge of the leaf, where the concave side has only slightly fewer pores than the convex side. *Sphagnum imbricatum* is the only member of Section *Sphagnum* that has more than just a few pores on the concave side (excluding the edge of the leaf). Pores are only found in the middle and upper portions of the leaf, and not the basal portion.

Sphagnum squarrosum has about twice as many pores on the concave side of the leaf as on the convex side of the leaf. Most of the concave pores are in the tip of the leaf. There are no concave pores in the basal portion of the leaf, but there are convex pores. Pore frequency in the tip of *S. squarrosum* is four times greater on the concave side than on the convex side.

Sphagnum wulfianum pores, especially leaf tip pores, are different from those in other groups. The convex pores are small, elliptical, with a more distinct border than other species. Convex tip pores are numerous, while concave tip pores are almost nonexistent. Overall in *S. wulfianum*, the concave side of the leaf has few pores, except on the edge.

Species in Section *Acutifolia* have pore patterns similar to those of species in Section *Sphagnum*. There are more pores on the convex side than on the concave side on all parts of the leaf. Pores are most numerous in *S. girgensohnii* on both concave and convex sides. In *S. fuscum* and *S. girgensohnii*, convex pores have approximately the same frequency on all parts of the leaf. On the concave side, pores are found mostly on the tip and on the edge of the leaf. All three species in the Section *Acutifolia* have the same edge pore frequency. Significant differences between species for pore frequency could not be determined because variances were not equal (table 4.3.3.9 and 4.3.3.10).

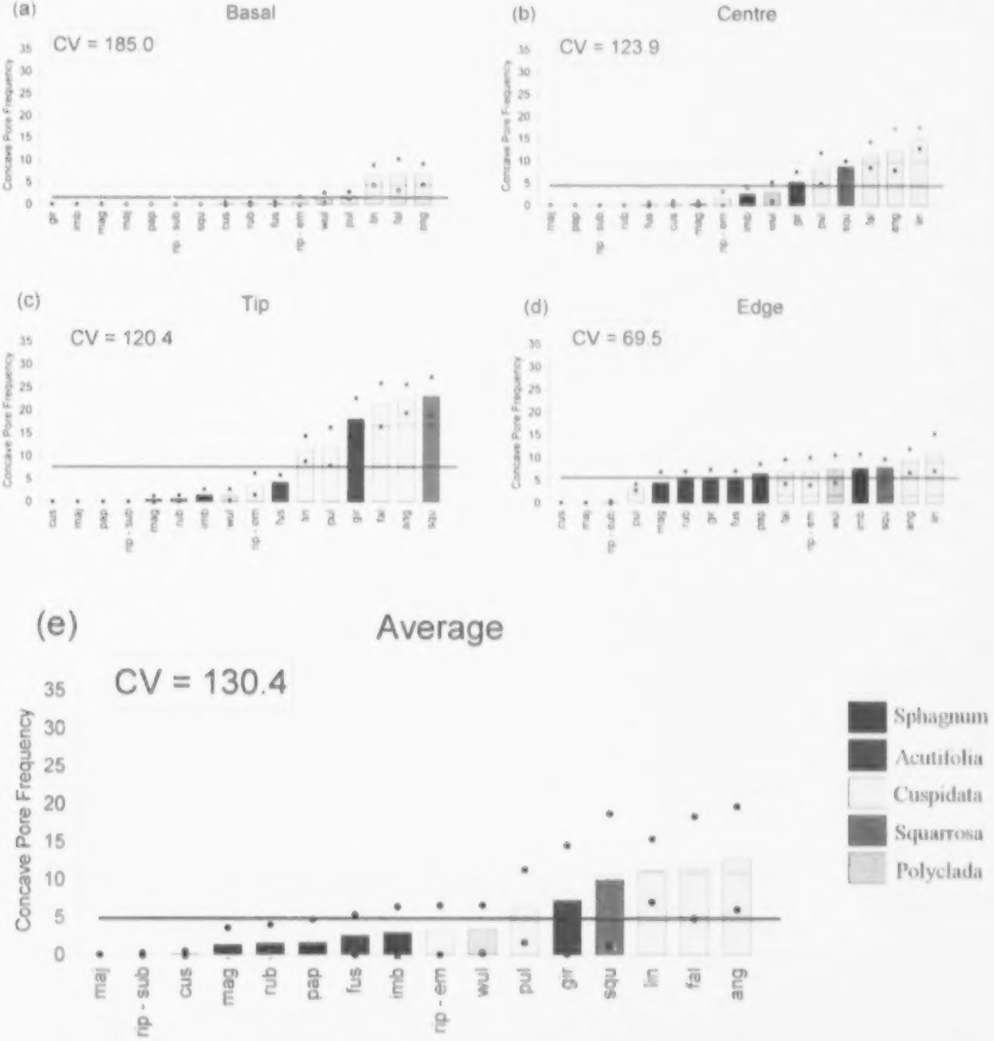


Figure 4.3.3.3. Concave pore frequencies of *Sphagnum* per 105 µm (a) on base of leaf (b) in centre of leaf (c) on tip of leaf (d) on edge of leaf (e) mean of all parts of leaf. Species are indicated by first three letters of the specific epithet as per table 4.3.3.9. Heavy line is mean of all species. Upper line is one standard deviation from mean. Closed circles are one standard deviation from mean of individual species. CV = Variation Coefficient.

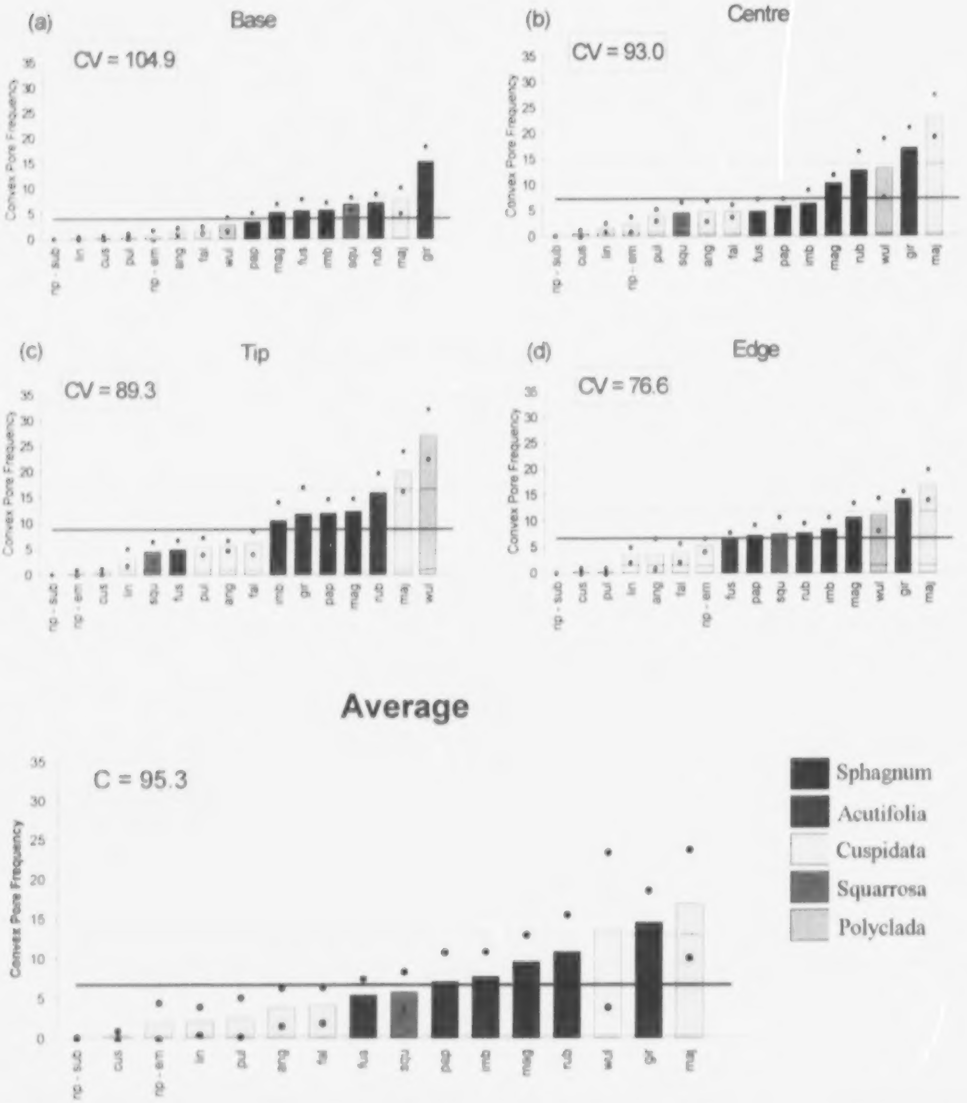


Figure 4.3.3.4. Convex pore frequencies of *Sphagnum* per 105 µm (a) on base of leaf (b) in centre of leaf (c) on tip of leaf (d) on edge of leaf (e) mean of all leaf parts. Species are indicated by the first three letters of the specific epithet as per table 4.3.3.18. Solid line is mean of all species. Upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from the mean of individual species. CV = Variation Coefficient.

Table 4.3.3.9: Concave pore frequency on base, centre, tip and edge of leaf, and mean of all parts of leaf. M = mean number of pores per 105 micrometres, V = variance. Ten leaves were sampled for each species, except *S. riparium* (emergent) where nine leaves were sampled.

Species	Base		Centre		Tip		Edge		Mean	
	M	V	M	V	M	V	M	V	M	V
S. angustifolium	6.8	5.5	12.6	21.6	22.5	9.8	9.3	7.1	12.8	46.7
S. cuspidatum	0.1	0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.1	0.1
S. fallax	6.7	12.5	11.4	8.3	21.1	22.3	6.9	7.2	11.5	46.6
S. fuscum	0.2	0.2	0.2	0.2	4.3	2.2	5.6	2.0	2.6	7.1
S. girgensohnii	0.0	0.0	5.3	4.9	18.1	20.3	5.5	3.4	7.2	52.0
S. imbricatum	0.0	0.0	2.6	1.8	1.5	1.4	7.7	9.6	3.0	11.5
S. lindbergii	6.6	4.9	15.2	5.5	11.6	7.6	11.2	16.8	11.2	17.6
S. magellanicum	0.0	0.0	0.4	0.3	0.5	0.5	4.5	5.4	1.4	4.8
S. majus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. papillosum	0.0	0.0	0.0	0.0	0.0	0.0	6.5	4.3	1.6	9.1
S. pulchrum	2.0	0.7	8.3	12.5	12.0	17.3	3.4	0.5	6.4	23.4
S. riparium (emergent)	0.6	1.3	1.6	2.5	3.9	5.6	7.0	9.3	3.3	10.6
S. riparium (submerged)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
S. rubellum	0.1	0.1	0.0	0.0	0.7	0.5	5.4	2.3	1.6	5.8
S. squarrosum	0.0	0.0	8.8	1.3	23.1	17.4	8.0	2.9	10.0	76.0
S. wulfianum	1.4	1.4	3.0	4.7	1.5	1.6	7.5	9.4	3.4	10.2

Table 4.3.3.10: Convex pore frequency on base, centre, tip and edge of leaf, and mean of all parts of leaf. M = mean number of pores per 105 micrometres, V = variance. Ten leaves were sampled for each species, except *S. riparium* (emergent) where nine leaves were sampled.

Species	Base		Centre		Tip		Edge		Mean	
	M	V	M	V	M	V	M	V	M	V
S. angustifolium	1.4	0.5	4.8	4.0	5.6	0.9	3.6	8.5	3.9	5.8
S. cuspidatum	0.2	0.2	0.4	0.5	0.5	0.3	0.3	0.2	0.4	0.3
S. fallax	1.7	0.5	4.8	1.5	6.1	5.0	3.8	3.3	4.1	5.0
S. fuscum	5.5	4.9	4.8	5.3	4.9	3.0	6.4	1.6	5.4	3.8
S. girgensohnii	15.1	8.5	17.0	15.1	11.7	26.9	14.1	1.9	14.5	15.8
S. imbricatum	5.6	2.0	6.3	6.5	10.5	11.6	8.4	4.7	7.7	9.5
S. lindbergii	0.1	0.1	1.6	0.7	3.3	2.7	3.4	2.3	2.1	3.2
S. magellanicum	5.2	2.6	10.2	2.4	12.2	5.7	10.6	7.4	9.6	11.2
S. majus	7.4	6.5	23.2	16.6	19.9	15.7	16.8	8.6	16.8	46.6
S. papillosum	3.4	2.5	5.8	1.7	11.9	7.0	7.2	3.7	7.1	13.3
S. pulchrum	0.5	0.3	4.0	1.3	5.5	2.7	0.3	0.2	2.6	6.2
S. riparium (emergent)	0.6	1.2	2.2	2.2	0.2	0.4	5.3	1.6	2.1	5.4
S. riparium (submerged)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. rubellum	7.0	2.9	12.7	12.9	15.8	14.2	7.7	3.1	10.8	21.1
S. squarrosum	6.8	1.5	4.5	4.1	4.5	3.4	7.5	9.6	5.8	6.1
S. wulfianum	2.8	2.0	13.1	32.5	27.2	24.2	11.1	9.9	13.6	94.8

Pore Area

Sphagnum girgensohnii and *S. squarrosum* have the largest total pore area (figure 4.3.3.5). *Sphagnum cuspidatum* has no measurable pores. *Sphagnum riparium*, growing submerged, has almost no pores, while emergent *S. riparium* has pores. *Sphagnum majus*, another species growing submerged, has a different pore pattern from the other species in Section *Cuspidata*; its pores are on the convex side of the leaf, whereas most pores are on the concave side of the leaf in other species in this section.

Pore area is related to subgeneric divisions of *Sphagnum*. Species in Section *Cuspidata* have a larger pore area on the concave side of the leaf (except for *S. majus*). In Section *Sphagnum*, there are few pores on the concave side of the leaf (except on the edge) *Sphagnum imbricatum* has a larger pore area than *S. papillosum* and *S. magellanicum* on the concave side, but a smaller pore area on the convex side. *Sphagnum papillosum* has concave pores only on the edge of the leaf (figure 4.3.3.6). Species of Section *Sphagnum* have a smaller pore area on the basal part of the leaf than on the centre, edge and tip. Pore area increases from base, centre, edge to tip of leaf in Section *Sphagnum* (figure 4.3.3.6).

In Section *Acutifolia*, pore area is greater on the convex side of the leaf. *Sphagnum girgensohnii* has the largest pore area on both the convex and concave sides of the leaf of the species in Section *Acutifolia*. *Sphagnum girgensohnii* pore areas have an opposite pattern on the convex side as compared to the concave side. On the concave side, the tip has the highest pore area, the centre and edge have a moderate amount and the base has none. On the convex side, the basal part of the leaf has the highest pore area, followed by the centre, edge and tip. This is the opposite of the pattern present in Section *Sphagnum*. *Sphagnum fuscum* and *S.* have a small pore area on the concave side as compared to the convex side, except on the leaf edge.

Species in Section *Cuspidata* have the smallest total pore area of all species except for *S. wulfianum*. *Sphagnum majus, S. angustifolium* and *S. fallax* have the highest total pore areas in the Section *Cuspidata*. *Sphagnum angustifolium* and *S. fallax* have very similar pore area patterns. Pore area on the concave side exceeds pore area on the convex side, with *S. majus* the only exception. On the concave side of the leaf, *Cuspidata* species tend to have the highest pore area on the tip, and the lowest on the basal part of the leaf.

Sphagnum squarrosum has the second highest total pore area, and the highest pore area on the concave side. Sixty percent of the pores in *S. squarrosum* are on the concave side and 40% on the convex. Thus, *S. squarrosum* pores are more evenly distributed on concave and convex sides than any other species. In most species, there is a considerably larger percentage of pores on one side than the other. *Sphagnum girgensohnii* has 66% of its pores on the convex side. *Sphagnum girgensohnii* has a similar pore area pattern *as S. squarrosum*, but lower values on the concave side and higher values on the convex side. In both of these species, the pore area decreases, from base to tip on the convex side, and increases from base to tip on the concave side.

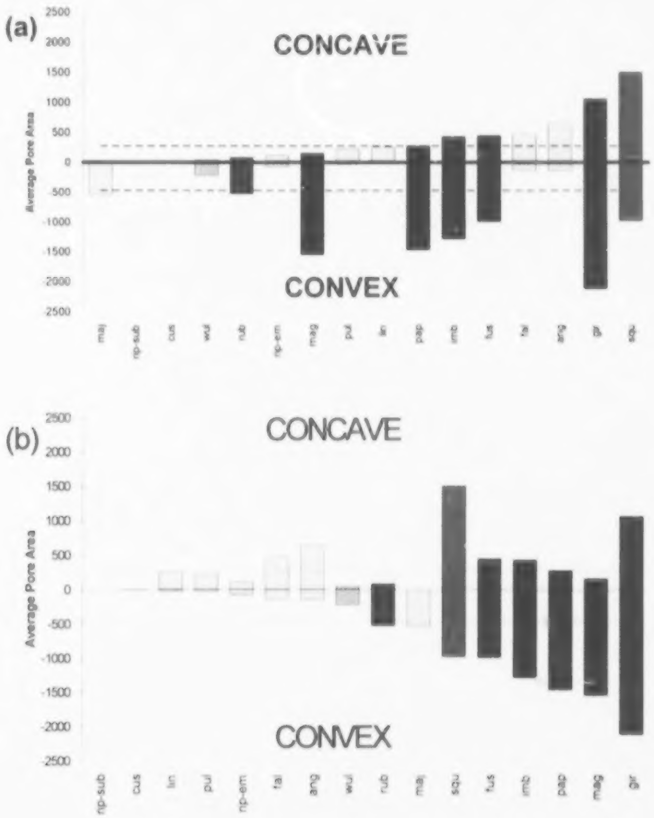


Figure 4.3.3.5. Mean pore areas on all parts of leaf in *Sphagnum* (in μm^2). Species names are represented by first three letters of specific epithet as in table 4.3.3.1. (A) shows pore areas in rank order of concave side (b) shows pore areas in rank order of convex side. Pore area is determined by using average pore diameter and average pore frequency for each species. Dashed line is the mean of that side. Negative values represent the pore area on the lower (convex) side of the leaf, positive values on the upper (concave) side of the leaf.

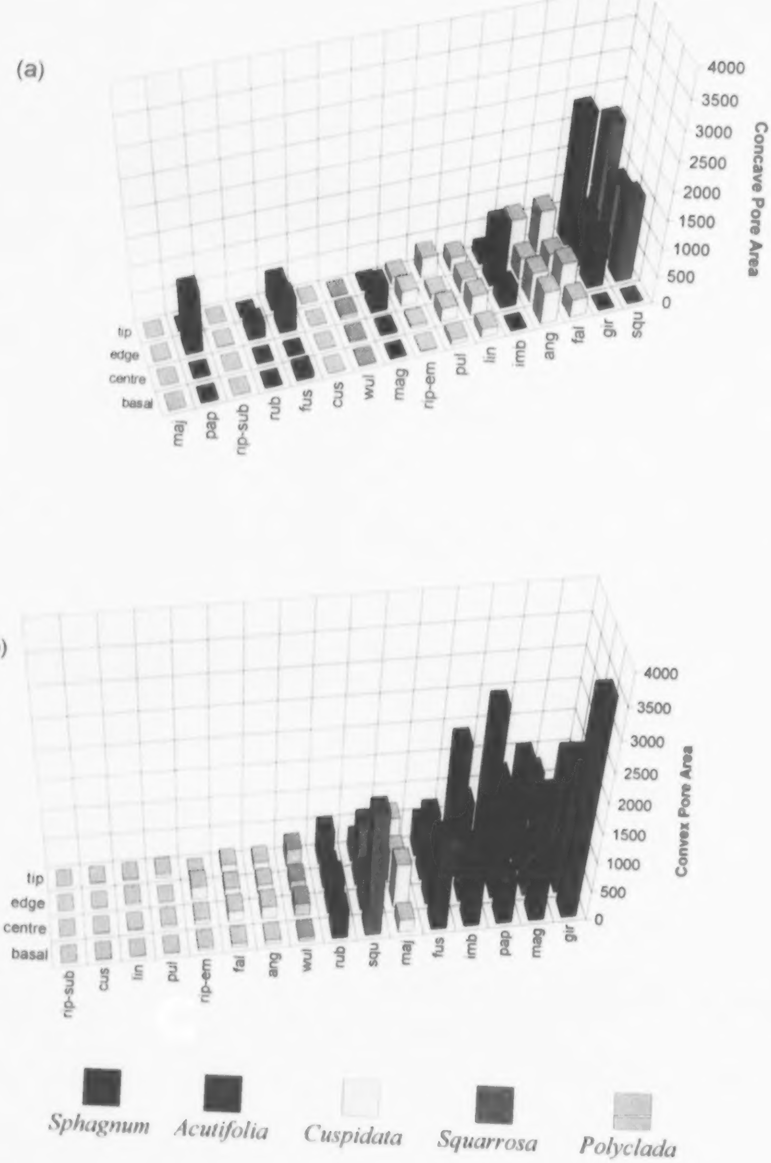


Figure 4.3.3.6. Pore area (μm^2) on the base, centre and tip of leaf (a) on concave side and (b) on convex side. Species names are represented by first three letters of specific epithet as in table 4.3.3.1. Pore area was determined by using pore diameter and pore frequency information for each species.

4.3.4 Fibril Frequency

Fibril frequency variation among species is less than for any other morphological characteristic (figure 4.3.4.1). For most species, fibril frequency is highest in the tip of the leaf. In some species, such as *S. wulfianum* and *S. squarrosum*, there is crosshatching of the fibrils in the tip, further strengthening this part of the leaf. In the species of Section *Cuspidata*, fibrils are uniform and evenly spaced. In species of Section *Sphagnum*, there are fibrils which do not go all the way across a cell. This occurs more frequently near the tip of the leaf.

In *S. imbricatum*, a morphological feature known as "comb fibrils" occurs. These are not true fibrils, as they do not wrap around the hyaline cell. "Comb fibrils" were not counted as fibrils. They are ornamentation on the side walls of the hyaline cells (where the hyaline cell contacts the chlorophyllous cell). *Sphagnum papillosum* also has ornamentation (papillae) on the side wall of the hyaline cell.

Fibril frequency is correlated with the subgeneric divisions of *Sphagnum* (figure 4.3.4.1). Three species of Section *Cuspidata*, *S. majus*, *S. cuspidatum* and *S. lindbergii*, have the highest fibril frequency. In the Section *Cuspidata*, fibril frequency is not related to habitat within *S. riparium* since emergent *S. riparium* has a similar fibril frequency as submerged *S. riparium* (figure 4.3.4.1). In the Section *Cuspidata*, species which normally grow submerged (*S. cuspidatum* and *S. majus*) have the highest fibril frequency. Variances were unequal between species, so an analysis of variance could not be performed to determine if there are significant differences between species (table 4.3.4.1).

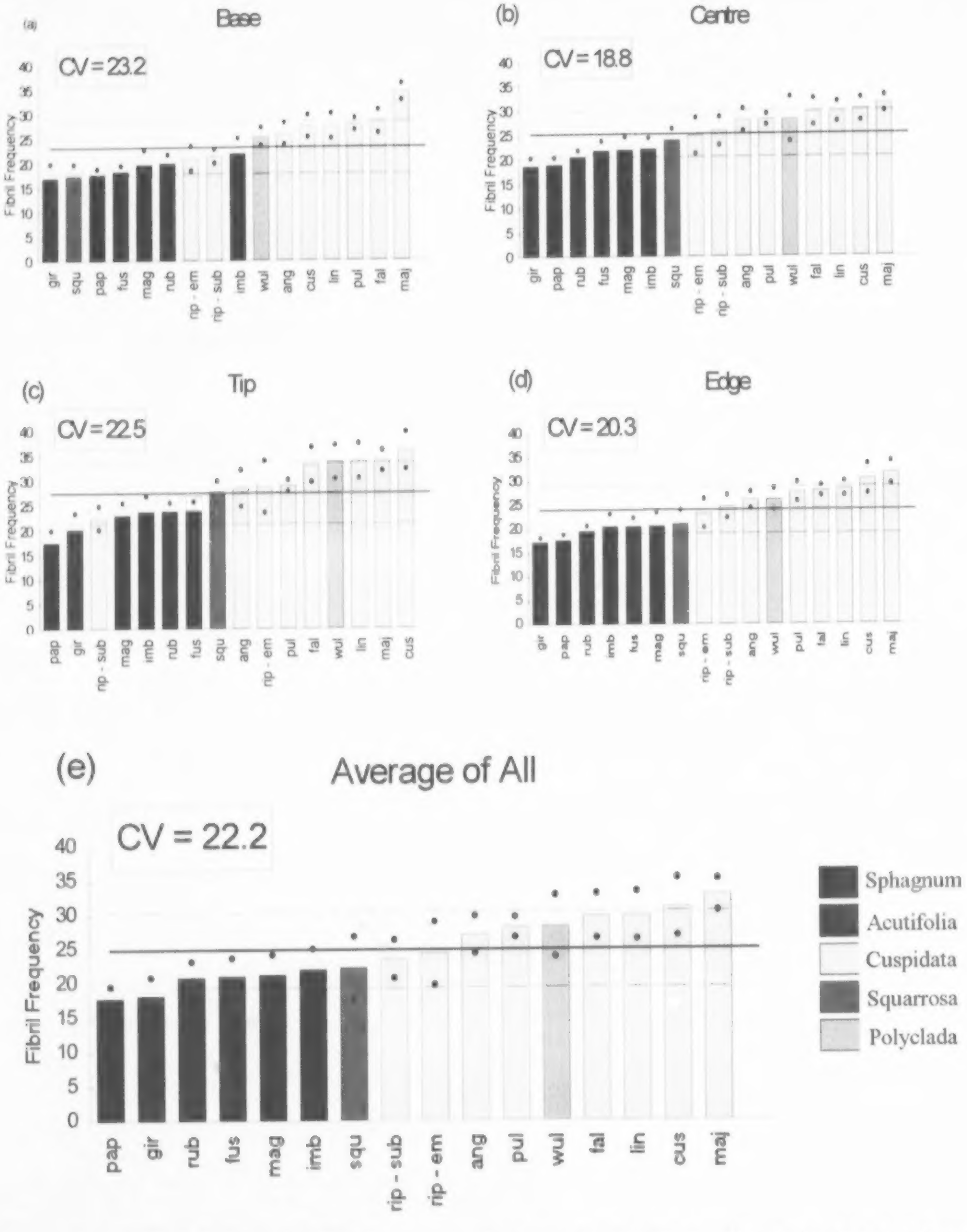


Figure 4.3.4.1: Fibril Frequencies in *Sphagnum* per 105 μm. Species are represented by first three letters of specific epithet, as listed in table 4.3.4.1. Centre line is mean of all species. Dashed lines are one standard deviation from mean. Closed circles are one standard deviation from means of individual species. CV = Variation coefficient.

Table 4.3.4.1: Fibril frequencies in *Sphagnum* per 105 μm on base, centre, tip and edge of leaf, and mean of all parts of leaf. M = mean number of fibrils per 105 μm, V = variance. Ten leaves were sampled for each species, except *S. riparium* (emergent) where nine leaves were sampled.

Species	Base		Centre		Tip		Edge		Mean	
	M	V	M	V	M	V	M	V	M	V
S. angustifolium	25.9	4.8	28.0	5.3	28.5	13.4	26.2	3.1	27.2	7.4
S. cuspidatum	27.4	5.2	30.1	5.4	36.0	13.8	30.6	8.9	31.0	17.7
S. fallax	28.3	5.6	29.6	7.4	33.2	12.2	28.1	1.2	29.8	10.4
S. fuscum	18.2	1.5	21.7	4.0	23.9	3.4	20.7	3.1	21.1	7.1
S. girgensohnii	16.9	8.8	18.6	2.7	20.2	10.2	17.4	0.7	18.3	6.8
S. imbricatum	21.8	10.4	22.1	5.2	23.7	10.2	20.7	6.8	22.1	8.7
S. lindbergii	27.4	6.3	29.6	4.0	33.9	12.1	28.6	2.0	29.9	12.0
S. magellanicum	19.6	9.4	21.9	7.2	23.0	6.2	20.8	7.7	21.3	8.7
S. majus	34.3	2.9	31.3	2.7	34.0	4.2	31.9	5.9	32.9	5.3
S. papillosum	17.5	1.6	18.9	2.1	17.5	6.1	17.8	1.5	17.9	2.9
S. pulchrum	27.8	1.5	28.1	1.2	29.0	1.3	27.9	4.1	28.2	2.1
S. riparium (emergent)	20.9	6.3	24.8	13.5	28.8	27.5	23.4	8.7	24.5	21.3
S. riparium (submerged)	21.3	2.0	25.8	8.2	22.5	5.6	24.8	5.7	23.6	8.1
S. rubellum	19.9	3.2	20.4	2.0	23.8	3.1	19.7	1.3	21.0	5.1
S. squarrosum	17.3	6.0	23.9	5.4	27.7	5.0	21.2	8.6	22.4	20.2
S. wulfianum	25.3	3.6	28.1	20.5	33.7	11.8	26.3	5.1	28.4	20.3

4.4 Hanging Branch Leaves versus Spreading Branch Leaves

There are two types of branches on a *Sphagnum* plant. In the fascicle, some branches hang near the stem (hanging branches), while others spread away from the stem (spreading branches). In some cases, such as *S. papillosum*, spreading and hanging branches are very similar in appearance. In other cases, such as *S. wulfianum*, spreading and hanging branches are dimorphic. In *S. wulfianum*, the spreading branches are short and stout and darkly pigmented in comparison to the long, slender hanging branches.

The degree of functional differentiation between hanging and spreading branches has not been examined. Whether or not morphology plays a role in functional differentiation, if it exists, is also unknown. However, if there is a morphological difference between hanging and spreading branches of plants that occupy different habitats, especially in plants from the same taxonomic section, this may be evidence of functional differentiation. Submerged species have less differentiation between hanging and spreading branches, and water moves only short distances to reach the tip of the plant for lawn species, and no distance in submerged species. In species that grow in areas where water availability is less certain, such as forests, differentiation between hanging and spreading branch leaves is expected. It is hypothesized that in some species specialized hanging branch leaves provide efficient wicking ability, and spreading branch leaves are specialized for photosynthesis and prevention of water evaporation.

By comparing the morphologies of spreading and hanging branch leaves, features important for the two different leaf functions may be differentiated.

4.4.1 Materials and Methods

Spreading and hanging branches were collected from the same fascicle for one individual of each species. Data were collected for seven species (*S. angustifolium* and *S. lindbergii* from Section *Cuspidata*, *S. magellanicum and S. papillosum* from Section *Sphagnum*, *S. fuscum* (Section *Acutifolia*), *S. wulfianum* (Section *Polyclada*) and *S. squarrosum* (Section *Squarrosa*)). Measurements for leaf length and width, hyaline cell length and width, pore diameter, pore frequency, pore patterns, and fibril frequency were taken. Except for pore patterns, data were collected in the same manner as for spreading branch leaves.

Results are presented for leaf length and width, hyaline cell length and width, pore diameter and number of pores per cell, pore frequency, pore area, and fibril frequency. The results are presented as a comparison of mean spreading branch leaf data to hanging branch leaf data. The pore and fibril frequency data are from branches from the same fascicle. The other data are not necessarily from the same individual fascicle, but are from the same subsample (consisting of about ten plants, from which spreading branch data was taken) of the population. Except for leaf pore diameters, data were presented in a similar fashion to the spreading branch leaf data. Following each figure is a table containing the values for each species and the coefficient of variation for each species, as well as these figures for all data combined.

Pore diameters are measured from the same cells that hyaline cell length was measured. Pore diameters are measured on the concave and convex sides of hanging and spreading branch leaves from branches collected from the same fascicle. The diameter of each pore was measured, and presented in a stem-leaf diagram. The mean and standard deviation of each group of data was determined.

Pore diameter data are presented as a stem-leaf diagram, showing the number of pores per cell, and the diameter of each pore from the base to the tip of the leaf. Concave and convex sides of the leaf are shown on the same stem leaf display. A corresponding stem leaf display of a spreading branch leaf is also shown for each species. From these displays, the pore patterns along the leaf are visualized, except for patterns on the edges.

SEM Analysis

Spreading and hanging branch leaves from the same fascicle were examined from samples of *S. riparium* (submerged and emergent), *S. lindbergii, S. fuscum, S. magellanicum, S. wulfianum, S. squarrosum, S. fimbriatum* Wils *ex* Wils & Hook., and *S. jensenii.* Fascicles of fresh moss were selected, and spreading and hanging branches separated. Branches were placed in liquid nitrogen, and freeze dried. Freeze-dried branches were placed on stubs, gold-coated (150 Angstroms thickness) and examined using a Cambridge S250 scanning electron microscope.

4.4.2 Results

Leaf Length And Width

In all species, spreading branch leaves are longer and wider than hanging branch leaves (figure 4.4.2.1). *Sphagnum squarrosum* has the longest hanging branch leaves (1.9 mm; table 4.4.2.1). However, the hanging branch leaves of *S. squarrosum* are twice as narrow as spreading branch leaves (figure 4.4.2.1). *Sphagnum angustifolium* has the shortest hanging branch leaves (0.8 mm). *Sphagnum papillosum* hanging branch leaves are the widest (0.8 mm), and *S. wulfianum* hanging branch leaves are the most narrow (0.2 mm).

Habitat may be important in differentiation between leaf size in hanging and spreading branch leaves. With *S. papillosum*, a wet lawn species in Section *Sphagnum*, there is little difference between the size of the spreading and hanging branch leaves. In another Section *Sphagnum* species, *S. magellanicum*, (a hummock former), the hanging branch leaves are less than half the length and width of the spreading branch leaves. *Sphagnum fuscum* (Section *Acutifolia*), another hummock species, has hanging and spreading branch leaves that are more similar to each other in size than other species. In addition, the hanging branch leaves of *S. magellanicum* and *S. fuscum* have similar widths, while the in the spreading branch leaves, *S. magellanicum* are twice as wide as those of *S. fuscum*.

Species in Section *Cuspidata* (*S. angustifolium* and *S. lindbergii*) have hanging branch leaves about one third shorter and one third less wide than spreading branch leaves). *Sphagnum wulfianum* hanging branch leaves are half as wide and one third shorter than spreading branch leaves.

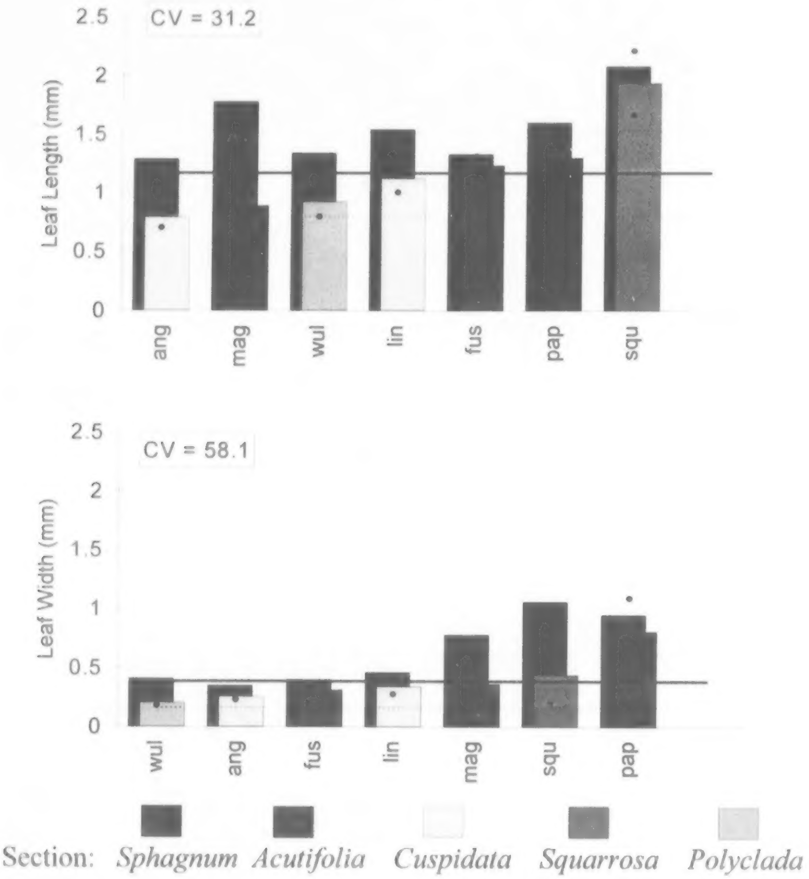


Figure 4.4.2.1. Length (top) and width (bottom) of hanging branch leaves of *Sphagnum* compared to spreading branch leaves. Foreground is hanging branch leaves and shaded background is mean values for spreading branch leaves. Centre line is mean of all hanging branch leaf lengths, upper and lower lines are one standard deviation. Closed circles are standard deviation of individual species. Species are wul = S. *wulfianum*, ang = *S. angustifolium*, fus = *S. fuscum*, lin = *S. lindbergii*, mag = *S. magellanicum*, squ = *S. squarrosum*, pap = *S. papillosum*.

Table 4.4.2.1: Leaf length and width (mm) of hanging branch leaves. N = 10 for all species (except *S. lindbergii*, where n = 20). CV = Variation Coefficient.

	SPECIES	MEAN	STD DEV	CV
Leaf Length	*S. angustifolium*	0.8	0.1	11.2
	S. fuscum	1.2	0.1	6.2
	S. lindbergii	1.1	0.1	10.6
	S. magellanicum	0.9	0.1	13.7
	S. papillosum	1.3	0.1	8.9
	S. squarrosum	1.9	0.3	14.2
	S. wulfianum	0.9	0.1	13.8
	ALL	1.2	0.4	31.2
Leaf Width	*S. angustifolium*	0.3	0.0	9.7
	S. fuscum	0.3	0.0	7.9
	S. lindbergii	0.3	0.1	19.7
	S. magellanicum	0.4	0.1	38.0
	S. papillosum	0.8	0.3	34.9
	S. squarrosum	0.4	0.2	55.2
	S. wulfianum	0.2	0.0	12.9
	ALL	0.4	0.2	58.1

HYALINE CELL SIZE

Hyaline cell widths are approximately the same width as spreading branch cells, with two exceptions (figure 4.4.2.2). *Sphagnum wulfianum*, has hanging branch hyaline cells that are more than one third wider than spreading branch hyaline cells. This may be to accommodate a larger pore size in the hanging branch leaves. *Sphagnum wulfianum* also has the most variable hyaline cell size (table 4.4.2.2). *Sphagnum angustifolium* hyaline cells from a hanging branch leaf are one fifth smaller than hyaline cells from a spreading branch leaf. *Sphagnum angustifolium* has the least variable hyaline cell width (table 4.4.2.2).

Hyaline cells are longest in the basal part of the leaf and shortest in the tip. Hyaline cell lengths are approximately the same in the hanging branch leaves as in the spreading branch leaves when the mean of all leaf parts is used (figure 4.4.2.3). The exception is *S. magellanicum*, where the standard deviation does not overlap with the mean of spreading branch hyaline cell lengths. In *S. magellanicum*, hanging branch leaf hyaline cells are approximately one third shorter than in spreading branch leaves. In this species, variation between all leaf parts is the lowest; approximately half that of other species (table

4.4.2.3). In species of Section *Sphagnum*, tip cell lengths are equivalent between the two species, but basal and centre hyaline cells are half as long in *S. magellanicum* than in *S. papillosum*.

Mean hyaline cell length in the tip of the hanging branch leaf is approximately the same for all species (about 85 μm). In other parts of the leaf, hyaline cell lengths are more widely variable ranging from 68 μm to over 150 μm.

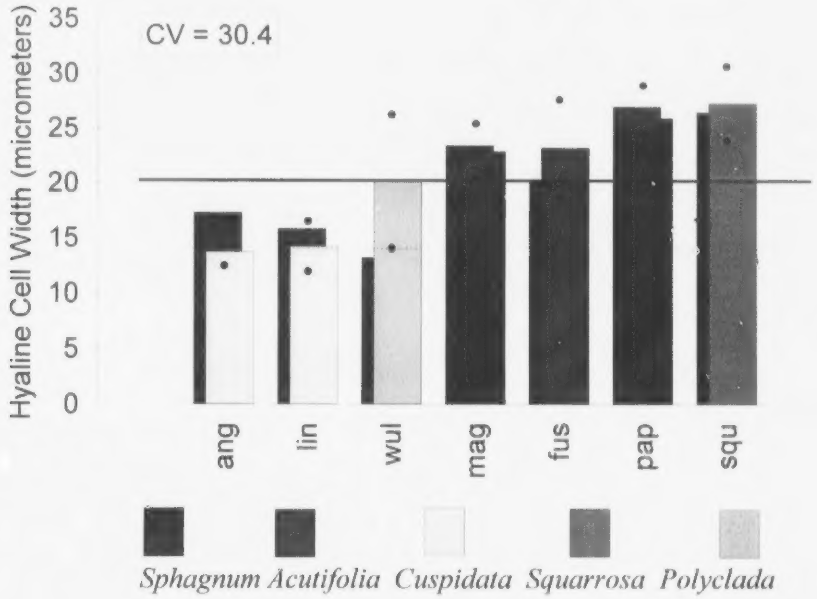


Figure 4.4.2.2: Hyaline cell widths (μm) of hanging branch leaves (foreground) compared to spreading branch leaves (shaded background). Centre line is mean of all hanging branch leaves and upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation coefficient. Species are ang = *S. angustifolium*, fus = *S. fuscum*, lin = *S. lindbergii*, mag = *S. magellanicum*, pap = *S. papillosum*, squ = *S. squarrosum*, wul = *S. wulfianum*..

Table 4.4.2.2: Hyaline cell widths of hanging branches of *Sphagnum*.. CV = Variation Coefficient. N = 10 for all species (20 for *S. lindbergii*).

SPECIES	MEAN	STD DEV	CV
S. angustifolium	13.8	1.3	9.1
S. fuscum	23.2	4.4	19.0
S. lindbergii	14.2	2.3	16.0
S. magellanicum	22.9	2.5	11.0
S. papillosum	25.9	3.0	11.5
S. squarrosum	27.3	3.4	12.4
S. wulfianum	20.2	6.1	30.3
ALL	**20.2**	**6.1**	**30.2**

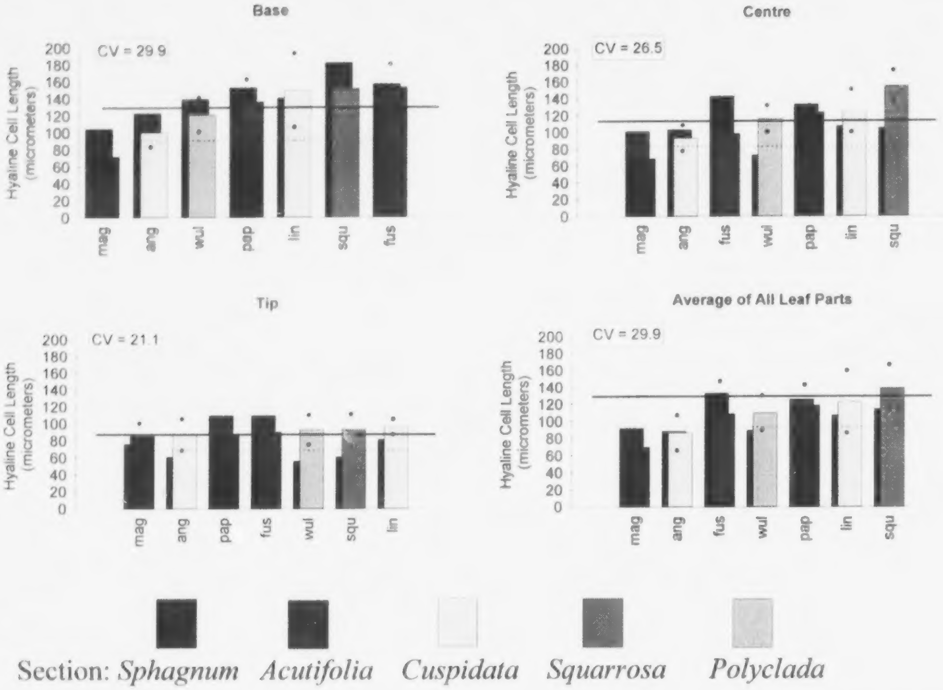


Figure 4.4.2.3: Hyaline cell lengths (µm) of hanging branch leaves (foreground) compared to spreading branch leaves (shaded background) on base, centre, and tip of leaf, and the mean of all leaf parts. Centre line is mean of all hanging branch leaves and upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from mean of individual species. CV = Variation coefficient. Species are ang = *S. angustifolium*, fus = *S. fuscum*, lin = *S. lindbergii*, mag = *S. magellanicum*, pap = *S. papillosum*, squ = *S. squarrosum*, wul = *S. wulfianum*..

Table 4.4.2.3: Hyaline cell lengths (µm) of *Sphagnum*. N = 5 for each leaf part of each species. CV = Variation Coefficient.

BASE	**MEAN**	**STD DEV**	**CV**	***CENTRE***	**MEAN**	**STD DEV**	**CV**
S. angustifolium	100.6	17.4	17.3	*S. angustifolium*	93.0	15.3	16.5
S. fuscum	152.7	27.1	17.8	*S. fuscum*	98.3	21.3	21.7
S. lindbergii	149.4	43.4	29.1	*S. lindbergii*	125.3	25.3	20.2
S. magellanicum	71.8	7.5	10.5	*S. magellanicum*	68.7	7.6	11.1
S. papillosum	135.9	26.3	19.3	*S. papillosum*	123.5	7.9	6.4
S. squarrosum	151.0	22.6	15.0	*S. squarrosum*	154.6	18.6	12.0
S. wulfianum	121.0	20.1	16.6	*S. wulfianum*	116.1	15.6	13.4
ALL	**129.0**	**38.6**	**29.9**	**ALL**	**113.1**	**30.0**	**26.5**
TIP				***MEAN***			
S. angustifolium	87.0	18.4	21.1	*S. angustifolium*	86.5	20.3	23.5
S. fuscum	90.1	17.4	19.3	*S. fuscum*	108.4	38.7	35.7
S. lindbergii	96.0	9.1	9.4	*S. lindbergii*	122.9	36.6	29.8
S. magellanicum	85.5	15.0	17.6	*S. magellanicum*	69.7	7.8	11.2
S. papillosum	88.1	15.7	17.9	*S. papillosum*	118.5	24.3	20.5
S. squarrosum	92.7	18.1	19.6	*S. squarrosum*	138.8	27.3	19.7
S. wulfianum	92.7	17.4	18.8	*S. wulfianum*	109.9	20.3	18.5
ALL	**87.0**	**18.4**	**21.1**	**ALL**	**129.0**	**38.6**	**29.9**

Pore Diameter And Pore Patterns

Section Sphagnum

In *S. magellanicum*, there are fewer pores per cell in the hanging branch leaves than in the spreading branch leaves (table 4.4.2.7). This is because the cells are shorter in the hanging branch leaves than in the spreading branch leaves. Pores are about 3 μm larger in the hanging branch leaves than the spreading branch leaves of both *S. magellanicum* and *S. papillosum* (tables 4.4.2.7 and 4.4.2.8). In *S. magellanicum*, pore distribution was similar between the spreading and hanging branch leaves, except there were fewer cells with pores on the concave side of the leaf in the hanging branch. In *S. papillosum*, the convex pore patterns are nearly identical on the hanging and spreading branches. On the concave side, pores were not found on the spreading branch leaf, while the hanging branch leaf has pores on the tip of the leaf.

Section Acutifolia

In *Sphagnum fuscum*, there are several noticeable differences between the hanging and spreading branch leaves (table 4.4.2.6). On the spreading branch, the pores are much smaller on the concave side than on the convex side. On the hanging branch, concave and convex pores are approximately the same size. On the spreading branch leaves, the concave side of the leaf has few pores, while in the hanging branch leaf there are about half as many pores on the concave side as on the convex side.

Section Cuspidata

In *S. angustifolium*, on the convex side of the leaf, cells usually have one large pore on the (distal) end of the cell. In the hanging branch, these pores have twice the diameter of the spreading branch leaves. The pores on the concave side are approximately the same between the hanging and the spreading branch leaves (table 4.4.2.4).

In *Sphagnum lindbergii*, the convex pores are larger on the hanging branch leaf than on the spreading branch leaf (table 4.4.2.5). As in *S. angustifolium*, the pores on the concave side are approximately the same size in both leaf types. Convex pore patterns of *S. lindbergii*, apart from the differentiation in cell size, are about the same on the spreading branch as the hanging branch. Concave pores are very numerous in the spreading branch, but the hanging branch leaf has only about one per cell.

Section Squarrosa

Pore patterns differ between the spreading and hanging branches of *S. squarrosum*. For one, there are many more pores per cell on the hanging branch leaves than on the spreading branch leaves. On the hanging branch leaf, the convex pores are larger than the concave pores. On the hanging branch leaves, the concave and convex pores are approximately the same size. On the spreading branch leaf, there is only one or two pores per cell on the centre and tip portions of the leaf, while the base has numerous pores per cell. On the hanging branch, there are numerous pores in all cells on the convex side. On the concave side, the spreading branch leaf has fewer pores per cell, but the overall distribution pattern is approximately the same as on the spreading branch. On the concave side, neither leaf has pores on the first few basal cells.

Section Polyclada

Pore patterns on the hanging branch leaves of *S. wulfianum* are very different from those on the spreading branch leaves. Pores on the hanging branch are at least three times larger than those on the spreading branch leaves. On the hanging branch, pores are distributed throughout the leaf except on the end of the tip on both sides, and the first two basal cells on the concave side. This pattern is similar to the hanging branch leaves of *S. fuscum*.

On the spreading branch, pores are smaller on the convex side than on the concave side. On the concave side, most pores are on the centre and towards the tip of the leaf, while on the concave side most of the pores are near the base of the leaf, with almost no pores near the tip.

Stem-Leaf Display Of Branch Leaf Pore Patterns

The following stem-leaf type diagrams show the number of pores per cell and the size of each pore, beginning from cell #1 (basal cell in the centre of the leaf). Cell #2 is the next cell, proceeding towards the tip of the leaf (figure 4.4.2.4). The final cell is the last leaf tip cell that was discernible. Where possible (i.e., species in Sections *Sphagnum*, *Acutifolia* and *Squarrosa*, and the hanging branch leaf in Section *Polyclada*) the figures for the concave and convex sides of the leaf are from the same leaf. If not possible to see the pores on both sides of the leaf (i.e., species in Section *Cuspidata* and spreading branch leaf in Section *Polyclada*), two leaves as close as possible in length were chosen for the concave and convex measurements.

Table #: *SPECIES NAME*

Hanging (or Spreading) Branch Leaf Pores

	CONCAVE PORES	CONVEX PORES
Mean	9.2	13.5
Standard Deviation	1.2	5.3

					8.4	**1**		
				8.4	8.4	**2**	15.8	
			8.4	8.4	8.4	**3**	10.5	17.9
10.5	9.5	9.5	8.4	8.4	7.4	**4**	22.1	10.5

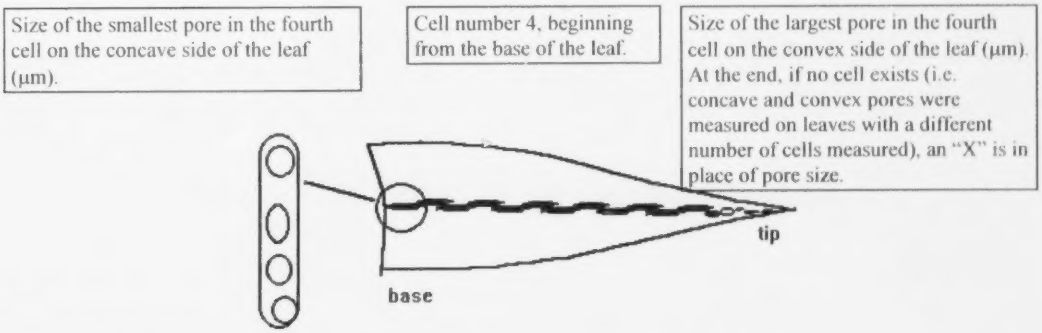

Size of the smallest pore in the fourth cell on the concave side of the leaf (μm).
Cell number 4, beginning from the base of the leaf.
Size of the largest pore in the fourth cell on the convex side of the leaf (μm). At the end, if no cell exists (i.e. concave and convex pores were measured on leaves with a different number of cells measured), an "X" is in place of pore size.
tip
base

Figure 4.4.2.4. Diagram explaining following stem-leaf diagrams.

Table 4.4.2.4: *Sphagnum angustifolium*

Hanging Branch Leaf Pores

	CONCAVE PORES	CONVEX PORES
Mean	9.2	13.5
Standard Deviation	1.2	5.3

					8.4	**1**				
				8.4	8.4	**2**	15.8			
			8.4	8.4	8.4	**3**	10.5	17.9		
10.5	9.5	9.5	8.4	8.4	7.4	**4**	22.1	10.5		
		8.4	9.5	9.5	9.5	**5**	10.5	21.0		
	10.4	9.5	9.5	9.5	9.5	**6**	10.5	10.5	10.5	21.0
	9.4	9.4	9.4	9.4	9.4	**7**	12.6	12.6	14.7	
		9.4	10.5	10.5	10.5	**8**	2.1	11.6	11.6	12.6
		10.5	9.4	9.4	9.4	**9**	3.2	10.5	12.6	13.7
			10.5	10.5	9.5	**10**	10.5	23.1		
			9.5	9.5	8.4	**11**	8.4	10.5	12.6	22.1
				9.4	9.4	**12**	10.5	21.0		
			8.4	8.4	3.2	**13**	21.0	12.6		

Spreading Branch Leaf Pores

Mean	6.1	7.6
Standard Deviation	1.6	1.6

			5.3	**1**	
				2	9.5
			5.3	**3**	8.4
			4.2	**4**	9.5
			10.5	**5**	7.4
	5.3	5.3	7.4	**6**	8.4
		4.2	5.3	**7**	8.4
9.5	7.4	5.3	5.3	**8**	
5.3	5.3	4.2	3.2	**9**	
		5.3	4.2	**10**	
	5.3	4.2	3.2	**11**	6.3
	6.3	6.3	5.3	**12**	5.3
	7.4	7.4	6.3	**13**	
8.4	6.3	6.3	6.3	**14**	7.4
		6.3	6.3	**15**	5.3

Table 4.4.2.5: *Sphagnum lindbergii*

Hanging Branch Leaf Pores

	CONCAVE PORES	CONVEX PORES
Mean	4.8	5.4
Standard Deviation	0.8	1.4

			5.3	**1**	4.2	8.4
			6.3	**2**	4.2	
4.2	4.2	4.2	4.2	**3**	3.2	5.3
			4.2	**4**	6.3	6.3
			5.3	**5**	5.3	
			5.3	**6**	4.2	6.3
				7	6.3	
			5.3	**8**	6.3	
			3.2	**9**	4.2	
			5.3	**10**		
			5.3	**11**		
		4.2	5.3	**12**		

Spreading Branch Leaf Pores

Mean	5.1	3.4
Standard Deviation	1.2	1.0

					11.6	6.3	5.3	**1**			
					7.4	6.3	3.2	**2**			
				8.4	7.4	5.3	3.2	**3**	4.2		
5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	**4**	4.2	4.2	
	5.3	5.3	5.3	5.3	5.3	5.3	5.3	**5**	4.2		
	6.3	6.3	5.3	5.3	5.3	5.3	5.3	**6**			
	5.3	5.3	5.3	5.3	5.3	5.3	4.2	**7**	2.1	2.1	3.2
		5.3	5.3	5.3	5.3	5.3	4.2	**8**			
		6.3	6.3	6.3	5.3	5.3	5.3	**9**	4.2		
				6.3	6.3	6.3	4.2	**10**	4.2	4.2	
		4.2	4.2	4.2	4.2	4.2	4.2	**11**			
		5.3	4.2	4.2	4.2	4.2	2.1	**12**	3.2		
		4.2	4.2	4.2	4.2	4.2	4.2	**13**	2.1		
					4.2	4.2	2.1	**14**	2.1		
					5.3	5.3	4.2	**15**			
					5.3	5.3	4.2	**16**			

Table 4.4.2.6: *Sphagnum fuscum*

Hanging Branch Leaf Pores

CONCAVE PORES CONVEX PORES

Mean	16.0	15.5
Standard Deviation	1.6	2.7

				1	18.9	18.9	23.1	23.1		
		16.8	15.8	**2**	15.8	17.9	20	21	21	
		14.7	14.7	**3**	14.7	15.8	15.8	15.8		
	14.7	14.7	14.7	**4**	14.7	15.8	15.8	15.8		
	15.8	15.8	13.7	**5**	13.7	13.7	16.8			
17.9	17.9	15.8	14.7	**6**	12.6	12.6	15.8	16.8		
	21	17.9	16.8	**7**	12.6	14.7	14.7	16.8		
	17.9	17.9	15.8	**8**	15.8	15.8	16.8	16.8		
		15.8	14.7	**9**	14.7	14.7	14.7	14.7	15.8	15.8
			15.8	**10**	12.6	13.7	15.8	15.8		
			13.7	**11**	10.5	10.5	15.8			
		15.8	14.7	**12**	12.6	13.7	13.7			
		16.8	16.8	**13**	11.6	12.6	12.6	14.7	14.7	

Spreading Branch Leaf Pores

Mean	14.5	19.1
Standard Deviation	6.1	3.0

	26.3	**1**	23.1	27.3				
		2	22.1	22.1	22.1			
		3	15.8	18.9	18.9	22.1	23.1	24.2
		4	15.8	16.8	16.8	17.9	20.0	
		5	18.9	18.9	21.0			
		6	18.9	20.0	21.0	22.1		
		7	15.8	16.8	16.8	18.9		
		8	17.9	18.9				
	13.7	**9**	12.6	14.7	15.8	15.8	17.9	18.9
	15.8	**10**	17.9	21.0				
	10.5	**11**						
10.5	10.5	**12**						

Table 4.4.2.7: *Sphagnum magellanicum*

Hanging Branch Leaf Pores

	CONCAVE PORES	CONVEX PORES
Mean	13.7	16.0
Standard Deviation	0	2.4

	1	15.8	20.0	22.1	
	2	16.8	17.9	18.9	
	3	16.8	16.8	17.9	17.9
	4	15.8	16.8	16.8	17.9
	5	12.6	13.7	15.8	
	6	10.5	12.6	17.9	17.9
	7	13.7	13.7	14.7	15.8
13.7	**8**	13.7	16.8	16.8	18.9
	9	10.5	15.8	17.9	
13.7	**10**	12.6	14.7	15.8	
	11	15.8	15.8	15.8	

Spreading Branch Leaf Pores

Mean	11.8	13.4
Standard Deviation	2.0	3.7

	1	22.1	22.1				
	2	16.8	18.9				
	3	11.6	12.6	14.7	18.9		
	4	11.6	11.6	11.6	11.6	12.6	18.9
	5	11.6	20.0				
	6	12.6	13.7	13.7	13.7	14.7	16.8
10.5	**7**	10.5	11.6	14.7			
10.5	**8**	12.6	24.2				
12.6	**9**	14.7	14.7	15.8			
11.6	**10**	10.5	10.5	14.7			
12.6	**11**	12.6	12.6	15.8	16.8		
12.6	**12**	10.5	12.6	15.8	16.8		
7.35	**13**	6.3	13.7	14.7	14.7		
12.6	**14**	10.5	11.6	11.6	12.6	12.6	
	15	12.6	12.6				
	16	7.35	10.5	10.5	12.6		
	17	5.25	11.6	11.6	13.7		
14.7	**18**	5.25	10.5	14.7	15.8		
12.6	**19**	5.25	12.6	15.8	16.8		

Table 4.4.2.8: *Sphagnum papillosum*

Hanging Branch Leaf Pores

	CONCAVE	CONVEX
Mean	17.0	17.0
Standard Deviation	1.9	2.3

			1	21.0	21.0					
			2	18.9	21.0					
			3	15.8	21.0					
			4	12.6	14.7	15.8	15.8	15.8	18.9	
			5	15.8	15.8	21.0				
			6	20.0	23.1					
			7	15.8	16.8	16.8	16.8	20.0		
			8	15.8	16.8	16.8	17.9	18.9	18.9	21
			9	11.6	12.6	16.8	17.9	17.9		
		18.9	**10**	16.8	17.9	18.9				
		14.7	**11**	14.7	16.8	16.8	18.9	21.0		
		17.9	**12**	15.8	15.8	15.8	17.9	22.1		
21.0	15.8	15.8	**13**	15.8	15.8	15.8	18.9			
17.9	15.8	14.7	**14**	12.6	15.8	15.8	15.8	16.8	17.9	
18.9	17.9	15.8	**15**	10.5	11.6	15.8	18.9	20.0		
		15.8	**16**	12.6	14.7	16.8				

Spreading Branch Leaf Pores

Mean	0	14.9
Standard Deviation	0	3.3

1	18.9	21.0					
2	15.8	15.8	16.8	18.9			
3	12.6	15.8	15.8	16.8	17.9	17.9	
4	11.6	12.6	13.7	16.8	17.9	17.9	
5	10.5	12.6	13.7	18.9			
6	12.6						
7	13.7	13.7	13.7	13.7	13.7	14.7	
8	12.6	15.8	15.8	16.8	17.9		
9	12.6	12.6	13.7	13.7	14.7	15.8	17.9
10	12.6	13.7	13.7	13.7	13.7	14.7	
11	11.6	13.7	13.7	13.7	14.7	14.7	
12	11.6	13.7	14.7	23.1			
13	10.5	13.7	13.7	13.7			
14	9.45	10.5	13.7	13.7	13.7	14.7	
15	10.5	13.7	13.7	13.7	13.7		
16	13.7	18.9	27.3				
17	15.8	29.4					

Table 4.4.2.9: *Sphagnum squarrosum*

Hanging Branch Leaf Pores

	CONCAVE	CONVEX
Mean	15.3	15.8
Standard Deviation	3.3	3.9

													1	16	19	20	21	21	22	24			
													2	18	19	19	20	21	21	25	26	27	
									16	16	16	16	***3***	16	16	17	18	18	21	21			
						20	17	15	15	14	12	11	***4***	14	15	15	15	17	18	18			
				18	17	17	17	16	16	16	16	15	***5***	16	16	17	17	22					
20	17	16	16	16	16	16	16	16	15	14	13	13	***6***	13	14	15	16	16	16	16	16	17	
		24	19	17	17	17	16	15	15	15	14	11	***7***	14	15	15	15	17	17				
19	18	18	18	17	17	17	16	16	16	16	16	14	***8***	14	16	16	16	16	17	18	19		
							17	17	16	16	16	14	***9***	14	16	16	16	17	19				
19	18	17	17	17	17	16	16	16	16	15	13	11	***10***	11	15	16	16	16	16	17			
			17	17	17	16	16	16	16	15	14	12	***11***	12	16	16	16	16	16	17	18	18	
	20	17	17	17	17	17	17	16	16	15	13	13	***12***	13	15	16	16	17	17	17	17	17	17
					18	17	17	17	16	16	14	13	***13***	8	13	14	16	16	17	17	17	18	
			18	16	16	16	16	16	16	15	15	15	***14***	15	15	16	16	16	16	16	16		
				18	18	16	16	16	16	16	16	16	***15***	16	16	16	16	16	16	16	18	18	
				23	19	19	18	17	17	16	16	13	***16***	12	16	16	16	17	19				
				19	18	18	17	17	16	16	16	15	***17***	16	16	17	17	18					
					19	17	16	16	13	12	11	11	***18***	11	11	13	16	16	19				

Spreading Branch Leaf Pores

Mean	15.6	18.3
Standard Deviation	4.1	5.8

								1	16	24							
								2	25	26	27						
								3	16	22	23	23	23	24	25	25	27
							23	**4**	21	23	23	23	23	23			
				20	19	17	16	**5**	19	21							
				22	21	19	17	**6**	18								
21	21	21	20	19	19	18	15	**7**	15	16	18						
		23	21	21	21	20	19	**8**	12								
		30	21	19	19	18	15	**9**	17								
		18	18	16	16	16	16	**10**	13	14							
	20	19	19	17	16	16	16	**11**	16								
			16	16	15	15	14	**12**	14								
			17	16	16	15	12	**13**	13								
			16	14	14	14	12	**14**	11								
			17	16	14	14	14	**15**	12								
			12	11	11	11	11	**16**	11	11							
				15	15	13	13	**17**	8	11							
		15	14	13	13	13	12	**18**	11	11							
				12	11	9	9	**19**	X								
				12	11	11	9	**20**	X								
					11	8	7	**21**	X								

Table 4.4.2.10: *Sphagnum wulfianum*

Hanging Branch Leaf Pores

	CONCAVE	CONVEX
Mean	14.3	17.9
Standard Deviation	3.0	4.1

					1	10.5	11.6			
					2	15.8	17.9	24.2		
			10.5	7.35	**3**	17.9	26.3			
		12.6	12.6	9.45	**4**	15.8				
15.8	14.7	14.7	12.6	12.6	**5**	15.8	16.8	17.9	18.9	
			16.8	15.8	**6**	15.8	20.0	21.0	31.5	
		17.9	15.8	12.6	**7**	17.9	20.0	21.0	21	
		21.0	15.8	14.7	**8**	17.9	17.9			
		16.8	15.8	12.6	**9**	12.6	14.7	15.8		
		20	16.8	12.6	**10**	16.8	16.8	16.8		
	16.8	12.6	11.6	10.5	**11**	13.7	21.0	21.0		
			15.8	14.7	**12**	12.6	13.7	16.8	17.9	21.0
					13					
					14					

Spreading Branch Leaf Pores

Mean	4.5	3.8
Standard Deviation	1.1	0.9

				1	6.3						
		5.3	5.3	**2**							
5.3	5.3	4.2	3.2	**3**							
5.3	5.3	5.3	3.2	**4**							
	5.3	4.2	3.2	**5**	5.3						
	3.2	3.2	3.2	**6**	3.2	4.2	4.2	4.2	4.2	5.3	6.3
		5.3	4.2	**7**	3.2	4.2	4.2				
		7.4	4.2	**8**	2.1	2.1	3.2	4.2			
			4.2	**9**	4.2	4.2	4.2	4.2			
				10	3.2	3.2	3.2	4.2	4.2		
				11	3.2	3.2	4.2	4.2	3.2	4.2	
				12	3.2	3.2	3.2				
			5.3	**13**	3.2	3.2	3.2				
			3.2	**14**	3.2	3.2	3.2				
				15	2.1	3.2					
				16	5.3						
				17	4.2	4.2	3.2				

PORE FREQUENCY

Variation among species is greater on the concave side than on the convex side (table 4.4.2.11). This is because on the concave side, several species have no pores on some areas of the leaf. In most species, the base of the leaf has fewest pores and the tip has the most pores. This is true on both sides of the leaf.

On the concave side of the leaf, pore frequencies are similar on hanging and spreading branch leaves, when the mean of all parts of the leaves is considered, except in *S. lindbergii* (figure 4.4.2.5). In *S. lindbergii*, pore frequency is lower on the hanging branch leaves than the spreading branch leaves on all parts of the leaf. On the convex side of the leaf, pore frequencies may be higher, lower, or similar in hanging and spreading branch leaves (figure 4.4.2.6).

The base of the leaf has the most similarity between pore frequencies of spreading and hanging branch leaves. In many species, there are few or no pores on the basal part of the leaf. At the base of the leaf, only in *S. lindbergii* is there a difference between the hanging and spreading branch concave pore frequency (fewer pores on the hanging branch leaf, figure 4.4.3.5). In the centre of the leaf, there is less similarity between the spreading and hanging branch leaves.

In *Sphagnum squarrosum*, there are more convex pores on hanging branch leaves than on spreading branch leaves, while species of Section *Cuspidata* have fewer pores on the hanging branch leaves than spreading branch leaves. In species of Sections *Acutifolia* and *Sphagnum*, there is no significant difference between the base and centre concave pore frequencies of the hanging and spreading branch leaves. These values are either zero or are low in comparison to other leaf parts. Most of the variation between the hanging and spreading branch leaves occurs in the tip of the leaf. On the edge of the leaf, only *S. wulfianum* (convex side) and *S. lindbergii* (concave side) have significantly fewer pores on the hanging branch as on the spreading branch.

On the convex side of the leaf (figure 4.4.2.5), there is a more variation between pore frequencies on the hanging and spreading branch leaves than on the concave side. In all species except for *S. wulfianum*, the hanging branch leaves have more convex pores than the spreading branch leaves.

Basal convex pores (figure 4.4.2.6) are more numerous in hanging branch leaves than in spreading branch leaves. On the base of the leaf, all hanging branch leaves have two to five times the number of pores as compared to the spreading branch, except in *S. fuscum*. Differentiation between spreading and hanging branches is greatest in Section *Sphagnum*, especially on the basal part of the leaf. On the centre and tip of the leaf, only *S. wulfianum* has more pores on the spreading branch leaf. On the edge of the leaf, there is less differentiation between spreading and hanging branch leaf convex pore frequency as compared to other parts of the leaf.

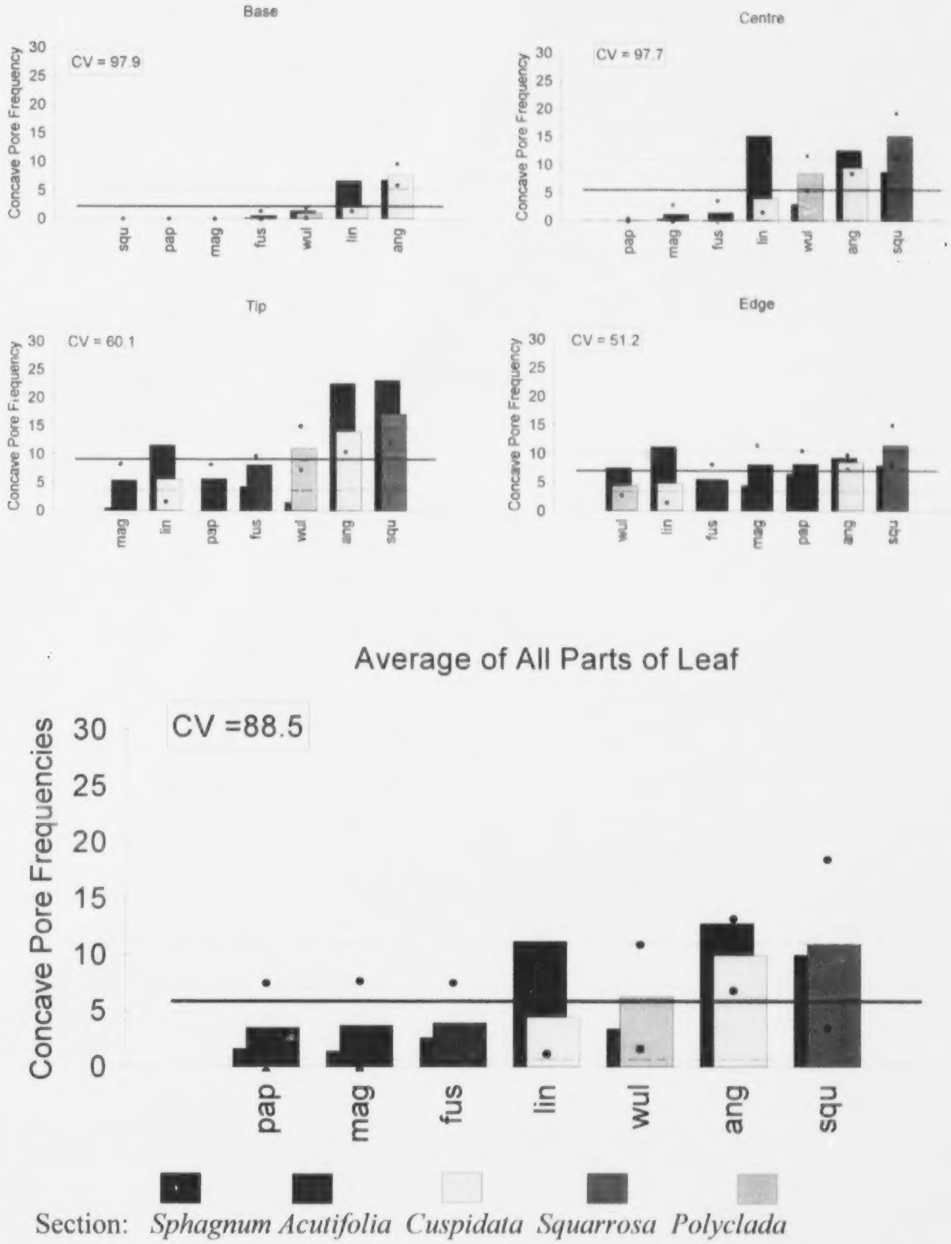


Figure 4.4.2.5: Concave pore frequencies of hanging branch leaves on base, centre, tip and edge of leaf, and mean of all leaf parts (foreground) and spreading branch pore frequencies from the same fascicle (background). Centre line is mean of all species. Upper and lower lines are one standard deviation from mean of all species. Closed circles are one standard deviation from mean of individual species. N = 10 for all species (except *S. lindbergii* where n = 20). CV = Variation Coefficient. Species are pap = *S. papillosum*, mag = *S. magellanicum*, fus = *S. fuscum*, lin = *S. lindbergii*, wul = *S. wulfianum*, ang = *S. angustifolium*, squ = *S. squarrosum*.

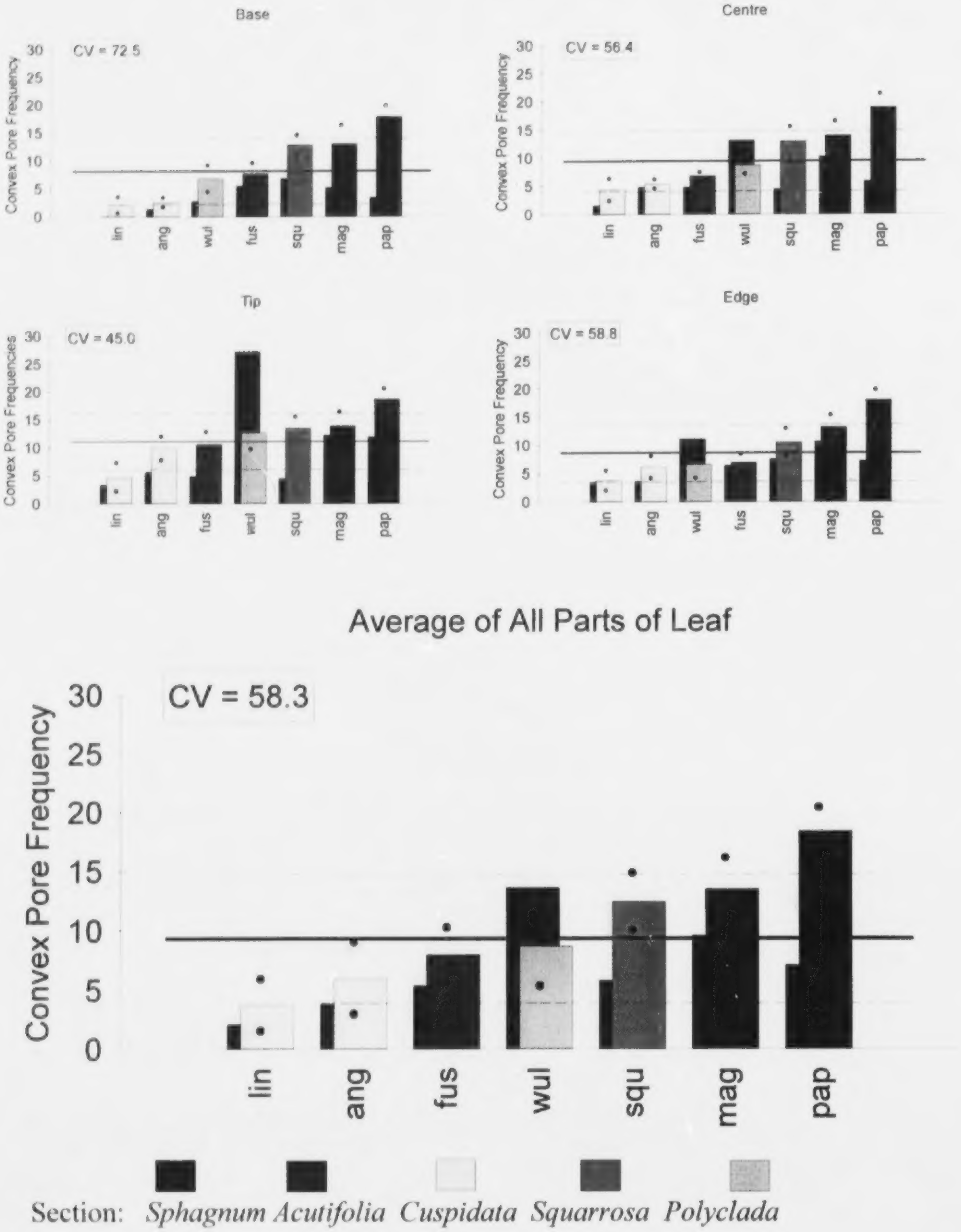


Figure 4.4.2.6: Convex pore frequencies of hanging branch leaves on base, centre, tip and edge of leaf, and mean of all leaf parts (foreground) and spreading branch pore frequencies from the same fascicle (background). Centre line is mean of all species. Upper and lower lines are one standard deviation from mean of all species. Closed circles are one standard deviation from mean of individual species. N = 10 for all species (except lindbergii where n = 20). CV = Variation Coefficient. Species are pap = *S. papillosum*, mag = *S. magellanicum*, fus = *S. fuscum*, lin = *S. lindbergii*, wul = *S. wulfianum*, ang = *S. angustifolium*, squ = *S. squarrosum*.

Table 4.4.2.11: Pore Frequencies on concave and convex sides of hanging branch leaf. N = 10 for all species (except *S. lindbergii* where n = 20). CV = Variation Coefficient.

	CONCAVE PORES			**CONVEX PORES**		
	MEAN	**STD DEV**	**CV**	**MEAN**	**STD DEV**	**CV**
mean						
S. angustifolium	10.0	3.2	32.2	6.0	3.0	50.6
S. fuscum	3.9	3.5	90.4	8.0	2.2	28.0
S. lindbergii	4.4	3.3	74.7	3.8	2.2	58.4
S. magellanicum	4.0	3.7	92.6	13.5	2.6	19.3
S. papillosum	4.0	3.5	88.4	18.4	2.0	11.0
S. squarrosum	11.0	7.5	68.9	12.4	2.4	19.5
S. wulfianum	6.3	4.7	74.4	8.7	3.4	38.5
ALL	**5.8**	**5.2**	**88.5**	**9.3**	**5.4**	**58.3**
base						
S. angustifolium	7.7	1.9	24.4	2.6	0.8	32.4
S. fuscum	0.7	0.6	76.5	7.7	1.9	24.5
S. lindbergii	2.0	0.7	35.4	2.1	1.5	70.6
S. magellanicum	0.0	0.0	0.0	13.0	3.3	25.6
S. papillosum	0.0	0.0	0.0	17.8	2.0	11.2
S. squarrosum	0.0	0.0	0.0	12.8	1.8	13.7
S. wulfianum	1.0	0.9	89.4	6.8	2.4	34.6
ALL	**2.1**	**3.1**	**144.9**	**8.1**	**5.9**	**72.5**
centre						
S. angustifolium	9.5	1.1	11.4	5.4	0.8	15.6
S. fuscum	1.5	2.1	137.9	6.8	0.6	9.3
S. lindbergii	4.1	2.5	62.3	4.4	2.0	44.5
S. magellanicum	1.2	1.6	134.9	13.9	2.6	18.4
S. papillosum	0.1	0.3	316.2	18.9	2.4	12.8
S. squarrosum	15.2	4.0	26.1	12.9	2.6	20.2
S. wulfianum	8.5	3.1	36.0	8.7	1.5	17.2
ALL	**5.5**	**5.4**	**98.0**	**9.4**	**5.3**	**56.4**
tip						
S. angustifolium	14.0	3.6	25.6	9.9	2.1	21.5
S. fuscum	8.1	1.5	18.8	10.6	2.2	21.0
S. lindbergii	5.6	4.0	72.2	4.8	2.6	53.7
S. magellanicum	5.4	2.8	52.5	13.9	2.6	18.4
S. papillosum	5.7	2.5	43.8	18.7	1.9	10.1
S. squarrosum	17.1	4.9	28.4	13.5	2.0	14.9
S. wulfianum	11.1	3.8	34.4	12.7	2.9	23.2
ALL	**9.1**	**5.5**	**60.1**	**11.1**	**5.0**	**45.0**
edge						
S. angustifolium	8.5	1.3	14.9	6.1	2.0	32.3
S. fuscum	5.5	2.5	46.4	3.8	1.7	46.5
S. lindbergii	4.9	3.5	71.2	6.9	1.5	22.1
S. magellanicum	8.1	3.3	40.5	13.2	2.1	16.3
S. papillosum	8.2	2.3	28.0	18.0	1.8	10.1
S. squarrosum	11.5	3.4	29.9	10.5	2.4	23.0
S. wulfianum	4.4	1.7	38.9	6.6	2.4	35.9
ALL	**7.0**	**3.6**	**51.2**	**8.6**	**5.1**	**58.8**

Pore Area

Section *Sphagnum*

Pore area is greater on the convex side of the hanging branch than the concave side for all leaf parts. On the concave side, pore area on the tip of the leaf is greater on the hanging branch than on the spreading branch (figure 4.3.3.6 and 4.4.2.6). On other parts of the leaf pore area is approximately equal between the two leaves. On the convex side, pore area is greater on the hanging branch than the spreading branch. Patterns are also different between the two leaves. In *S. papillosum,* convex pore area increases from the base of the leaf to the tip in the spreading branch. In the hanging branch, convex pore area is similar on all parts of the leaf (slightly less on the tip). In *S. magellanicum*, the same is true except that the base of the hanging branch has a slightly higher convex pore area rather than the tip. Figure 4.4.2.9 illustrates concave pores in a hanging branch leaf (h) of *S. papillosum*, and none in the spreading branch leaf (g). The difference in size of hanging and spreading branch leaves of *S. magellanicum* is also demonstrated (figure 4.4.2.9 e and d respectively)

Section *Acutifolia*

Pore area is greater on the convex side of the hanging branch leaf except on the edge of the leaf. On the concave side of the leaf, distribution patterns are similar between the spreading and hanging branch leaves, but the pore area is greater on the hanging branch than on the spreading branch. On the convex side, the same is true.

Section *Cuspidata*

In the hanging branch leaf, pore area is greater on the convex side than on the concave side for all leaf parts. The opposite is true in the spreading branch leaf. In *S. angustifolium*, there is usually a large convex pore at the end of a hyaline cell. There may or may not be other convex pores present. The convex pore at the end of the cell is larger in spreading branch leaves than in hanging branch leaves. In addition, there are more convex pores in hanging branch leaves than in spreading branch leaves.

The concave pore area of *S. angustifolium* is at least three times greater on the hanging branch than on the spreading branch. This, combined with convex pore results, is evidence of a functional differentiation between spreading and hanging branch leaves.

In *S. lindbergii*, concave pore area is greater on the spreading branch leaves than the hanging branch leaves. Convex pore area is about the same on both leaf types. However, pore area is much smaller in this species than in *S. angustifolium*. In addition, *S. lindbergii* has many pseudopores, which were not counted. This may be the reason for the small pore area of this species.

Section *Squarrosa*

In the basal part of the hanging branch leaf, pores are only present on the convex side. In all other parts of the leaf, pore area is greater on the concave side than on the convex side (figure 4.4.2.7). This is the same pattern as present on spreading branch leaves (figure 4.4.2.7 and 4.3.3.6). However, pore area is greater in the hanging branch leaves than in the spreading branch leaves for all parts of the leaf. The striking difference between spreading and hanging branch leaf shapes is illustrated in figure 4.4.2.9l. Spreading branch leaves are highly squarrose in comparison to the hanging branch leaves. Spreading branch leaves may be adapted to capture of water from the atmosphere, while hanging branch leaves are adapted to the upward wicking of water.

Section *Polyclada*

Pore area is substantially greater on the hanging branch leaves than on the spreading branch leaves. Basal concave pore area of the hanging branch leaf is one tenth of that present on the convex side (figure 4.4.2.7). Pore distribution patterns on other parts of the hanging branch leaf are similar for both sides, but pore area is greater on the convex side. Figure 4.4.2.9 illustrates the smaller pores on larger leaves in the spreading branch leaves (o) as compared to the hanging branch leaves (p).

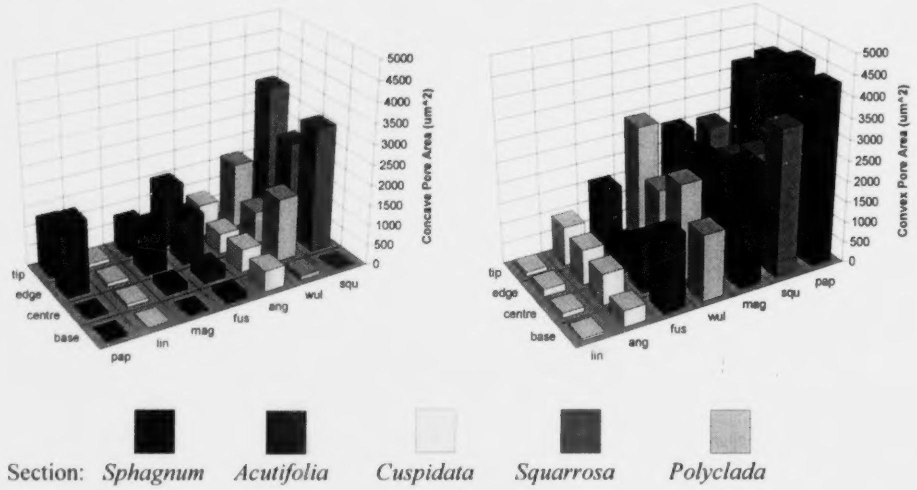


Figure 4.4.2.7: Average pore area of hanging branch leaves of *Sphagnum* (μm^2) on concave (top) and convex (bottom) side of the leaf. Area is determined using pore diameters and pore frequencies. For edge, centre pore diameter was used. Species are lin = *S. lindbergii*, ang = *S. angustifolium*, fus = *S. fuscum*, wul = *S. wulfianum*, mag = *S. magellanicum*, squ = *S. squarrosum*, pap = *S. papillosum*.

Fibril Frequencies

Fibril frequencies are approximately the same between hanging branch leaves and spreading branch leaves, except for in *S. wulfianum* and *S. squarrosum* (figure 4.4.2.8). In *S. wulfianum*, only the basal part of the hanging branch leaf has a similar fibril frequency to the spreading branch leaf. In all other parts of the leaf, the hanging branch leaf has fewer fibrils than the spreading branch leaf. This may be related to the fact that hanging branch leaves have much larger pores than spreading branch leaves in *S. wulfianum*, thus fibrils cannot be as frequent. The larger pores of the hanging branch leaves compared to spreading branch leaves is seen in figure 4.4.2.9 (o and p). The same pattern follows with *S. squarrosum*. In *S. angustifolium*, there is a higher fibril frequency in the basal part of the hanging branch leaf than the spreading branch leaf. This is the opposite of what is expected, since pores are larger in the spreading branch leaves.

Variation within a species is small, except for *S. fuscum* (table 4.4.2.12). In *S.* fuscum, the fibrils, especially near the tip of the leaf are often branched, and thus are complete annular fibrils are more difficult to count. Variation between species is greatest in the tip of the leaf.

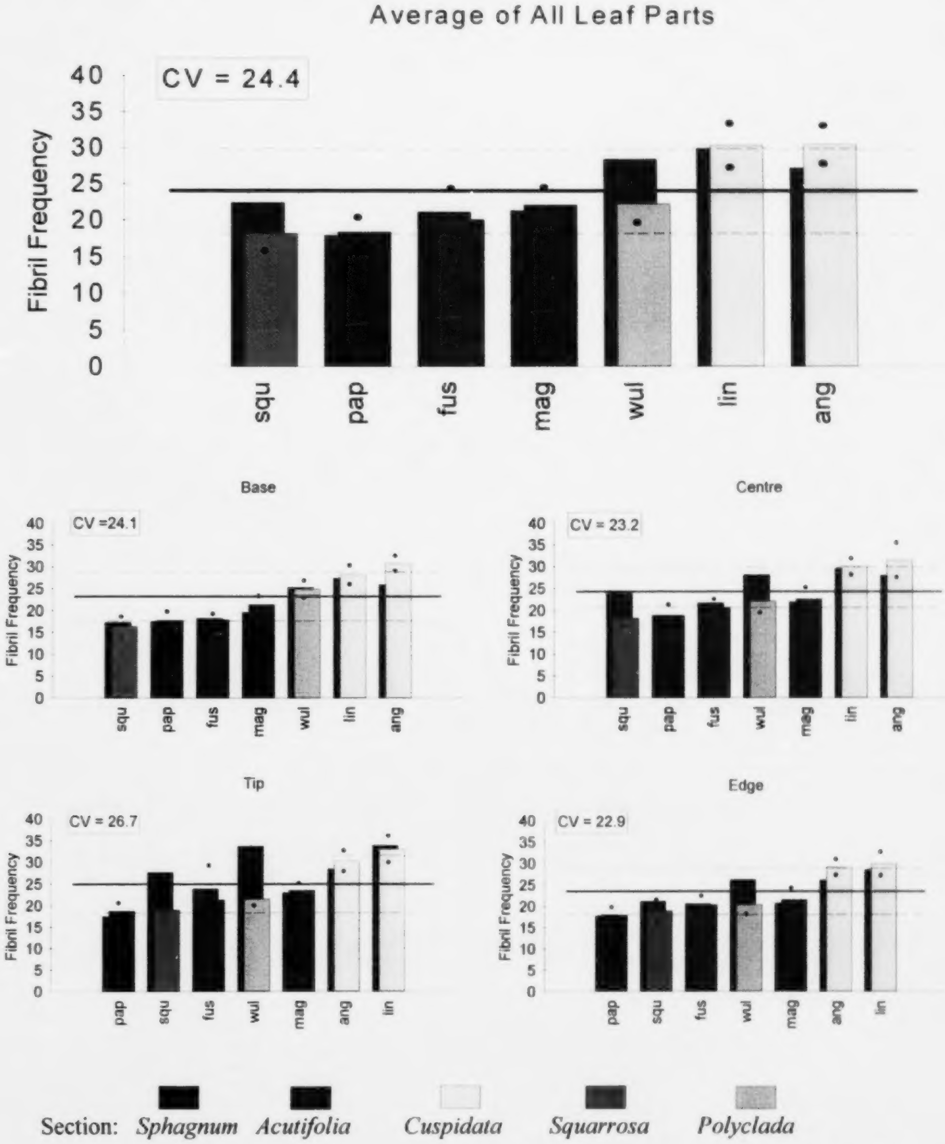


Figure 4.4.2.8: Fibril frequencies on the base, centre, tip and edge of hanging branch leaves compared to spreading branch leaves, and the mean for all parts of the leaf. Shaded bar is corresponding spreading branch leaf from same fascicle. Centre line is mean of all hanging branch values. Upper and lower lines are one standard deviation from the mean. Closed circles are one standard deviation from the mean of individual species. CV = Variation Coefficient. Species are ang = *S. angustifolium*, fus = *S. fuscum*, lin = *S. lindbergii*, mag = *S. magellanicum*, pap = *S. papillosum*, squ = *S. squarrosum*, wul = *S. wulfianum*.

Table 4.4.2.12: Fibril Frequencies. N = 10 (20 for lindbergii).
CV = Variation Coefficient

mean	**MEAN**	**STD DEV**	**CV**
S. angustifolium	30.5	2.7	8.7
S. fuscum	20.1	4.3	21.5
S. lindbergii	30.3	3.1	10.1
S. magellanicum	22.1	2.4	10.8
S. papillosum	18.4	2.0	11.0
S. squarrosum	18.2	2.3	12.9
S. wulfianum	22.3	2.6	11.7
ALL	**24.0**	**5.9**	**24.4**
base			
S. angustifolium	30.8	1.8	5.7
S. fuscum	17.9	1.4	7.7
S. lindbergii	28.2	2.1	7.6
S. magellanicum	21.3	2.0	9.4
S. papillosum	17.8	2.0	11.2
S. squarrosum	16.4	2.3	13.8
S. wulfianum	24.9	2.0	7.9
ALL	**23.2**	**5.6**	**24.1**
centre			
S. angustifolium	31.5	4.0	12.5
S. fuscum	20.7	1.9	9.1
S. lindbergii	30.1	1.9	6.2
S. magellanicum	22.6	2.6	11.7
S. papillosum	18.9	2.4	12.8
S. squarrosum	18.2	1.9	10.6
S. wulfianum	22.1	2.6	11.8
ALL	**24.3**	**5.6**	**23.2**
tip			
S. angustifolium	30.3	2.4	7.8
S. fuscum	21.3	8.0	37.4
S. lindbergii	33.1	3.1	9.3
S. magellanicum	23.5	1.7	7.3
S. papillosum	18.7	1.9	10.1
S. squarrosum	19.0	1.8	9.6
S. wulfianum	21.5	1.4	6.7
ALL	**24.9**	**6.7**	**26.7**
edge			
S. angustifolium	29.2	1.8	6.2
S. fuscum	20.4	2.1	10.1
S. lindbergii	30.0	2.7	9.0
S. magellanicum	21.6	2.7	12.6
S. papillosum	18.0	1.8	10.1
S. squarrosum	19.0	2.6	13.6
S. wulfianum	20.5	2.2	10.8
ALL	**23.5**	**5.4**	**22.9**

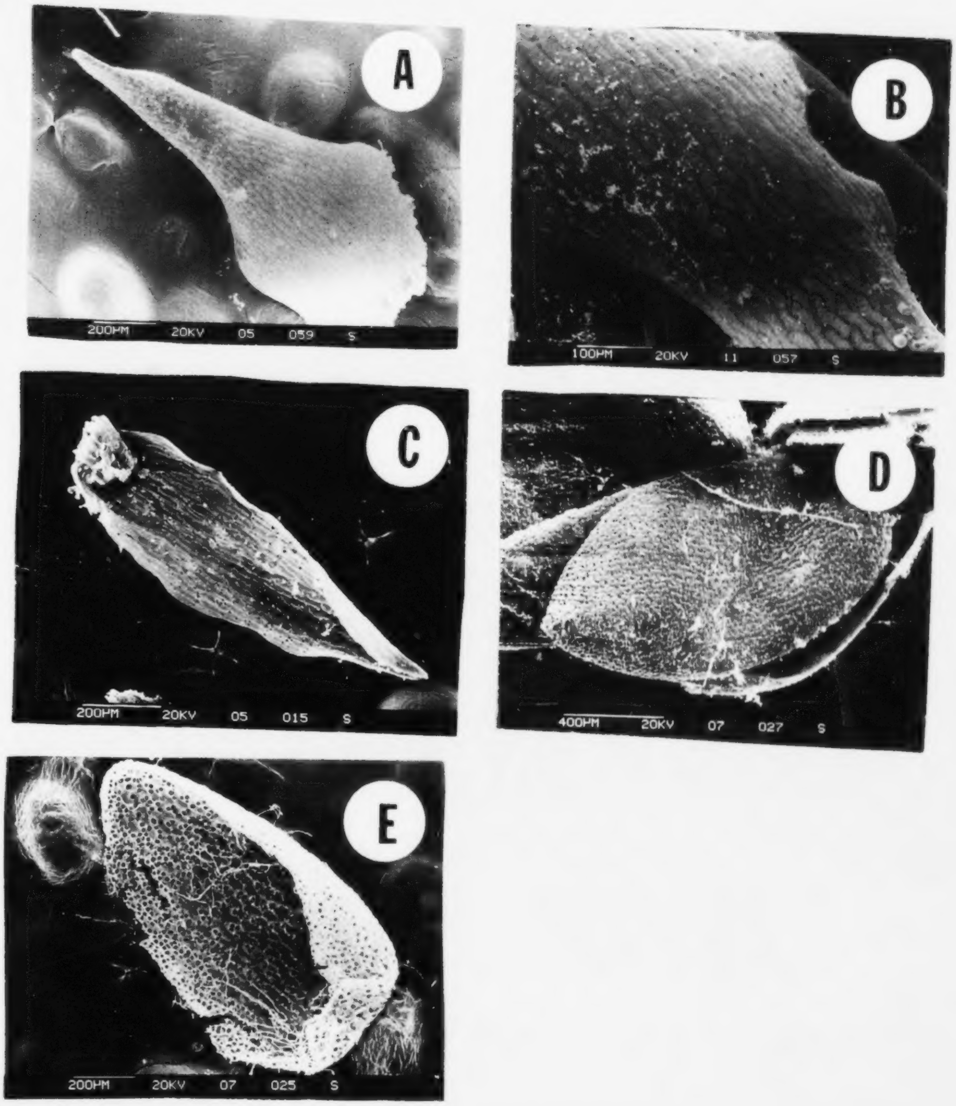
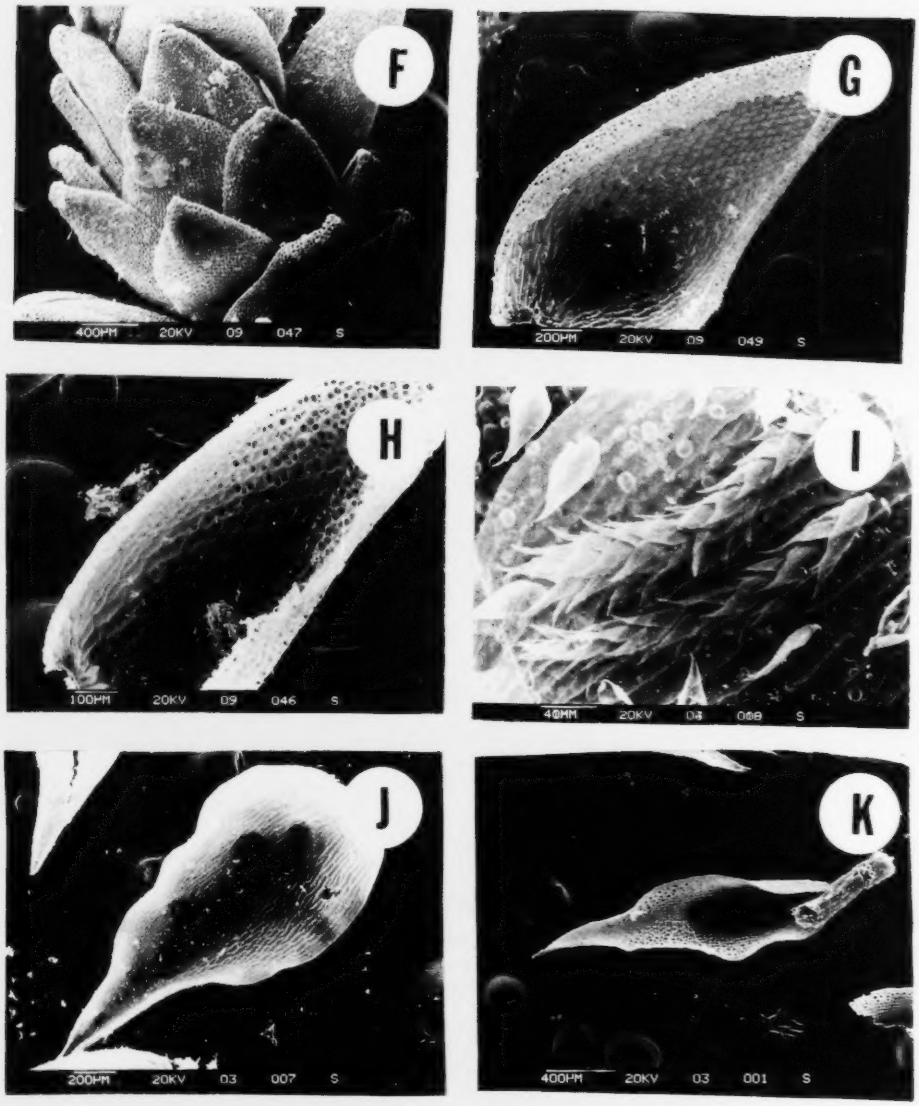

A
200μM 20KV 05 059 S
B
100μM 20KV 11 057 S
C
200μM 20KV 05 015 S
D
400μM 20KV 07 027 S
E
200μM 20KV 07 025 S

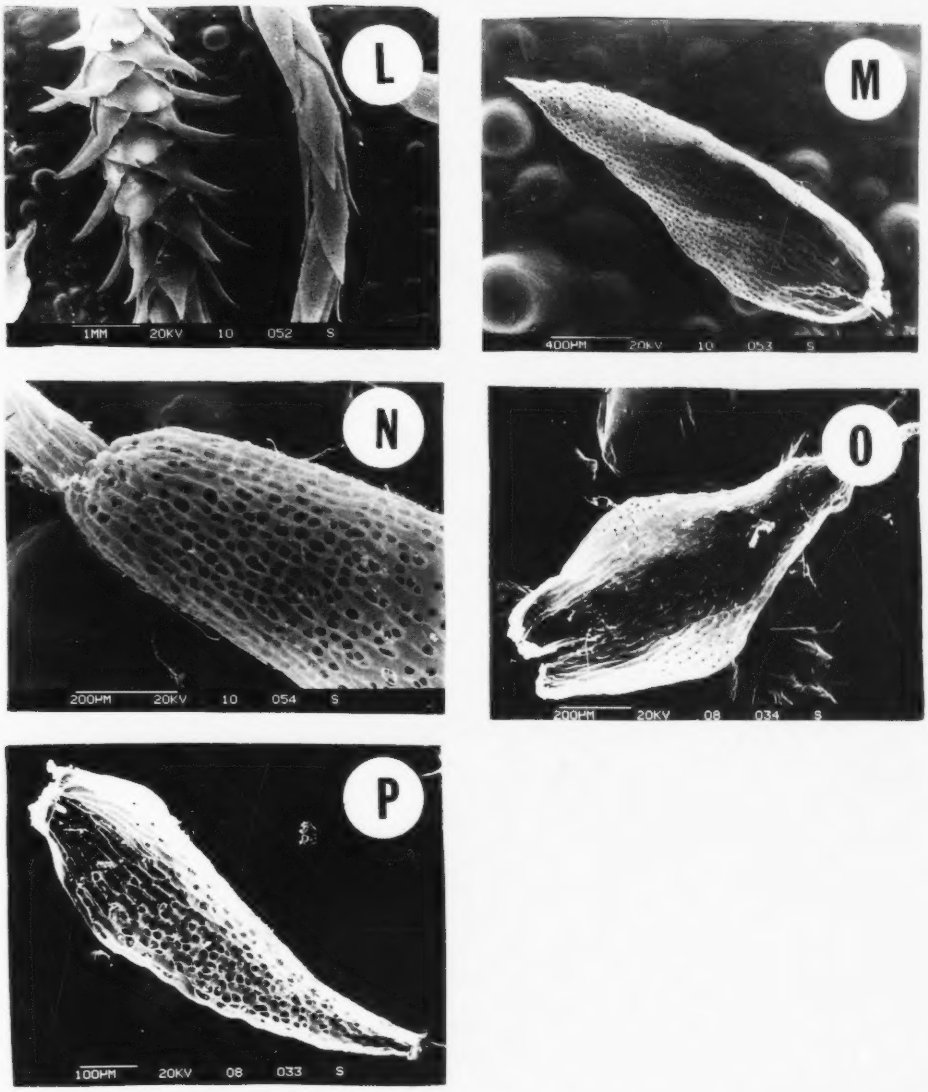
Figure 4.4.2.9: Comparison between hanging and spreading branch leaves.

(a-c) ***S. lindbergii*** (a) convex side of spreading branch leaf (b) middle portion of convex side of spreading branch leaf (c) concave side of hanging branch leaf. Note shape difference between hanging and spreading branch leaves.
(d-e) ***S. magellanicum*** (d) convex side of spreading branch leaf (e) concave (with some convex visible) side of hanging branch leaf. Note difference in size of two leaves.


F
400μm 20KV 09 047 S
G
200μm 20KV 09 049 S
H
100μm 20KV 09 046 S
I
40μm 20KV 03 008 S
J
200μm 20KV 03 007 S
K
400μm 20KV 03 001 S

(f-h) ***S. papillosum*** (f) overview of placement of spreading branch leaves. (g) Concave side of spreading branch leaf compared to (h) concave side of hanging branch leaf. The shape of the two leaves is similar, but the smaller hanging branch leaf has concave pores while the larger spreading branch leaf does not.

(i-k) ***S. riparium*** (i) upper branch is a spreading branch from emergent population; lower branch is hanging branch from emergent population. (j) Concave side of spreading branch leaf from a submerged population; (k) hanging branch leaf from the same fascicle. Note larger and more frequent pores in hanging branch leaf, and smaller width of hanging branch leaf.


L
1MM 20KV 10 052 S
M
400HM 20KV 10 053 S
N
200HM 20KV 10 054 S
O
200HM 20KV 08 034 S
P
100HM 20KV 08 033 S

(l-n) ***S. squarrosum*** (l) comparison between spreading (left) and hanging (right) branches. (m) concave side of hanging branch (n) convex side of hanging branch. Note the numerous large pores.

(o-p) ***S. wulfianum*** (o) spreading branch leaf (p) hanging branch leaf. Note larger size of spreading branch leaf, but larger pores in hanging branch leaf.

4.5 Summary and Conclusions

4.5.1 Conclusions and Discussion

Statistical Analysis

For some morphological characteristics of *Sphagnum*, there was significant difference between the three individuals chosen from the population. Thus, either the sample size (three individuals chosen at random from a subsample of the population consisting of about 100 individuals) was not adequate, or a large amount of variation within a population does exist. It is probably a combination of these two factors that is the case For example, Sastad and Flatberg (1993) noted that *S. strictum* leaf morphology is variable dependent on habitat.

There was no procedure in place to select the leaves chosen for measurements. For leaf size data, five to ten leaves were chosen at random (obviously juvenile leaves were excluded). Thus, there is variation not only between species, but within an individual plant. For the other measurements, steps should have been taken to ensure the three leaves from the three individual plants within the population were equivalent in size. This would probably have eliminated much of the variation that is seen in the data set, but would have meant that the data set represented only leaves of a certain size, rather than the variation within a population. However, using the more random selection method as was done, more individual samples should have been measured (at least ten individuals from each population, preferably more) to show the total amount of variation within the population. The frequency data were taken from ten leaves from the same fascicle, rather than from ten leaves from individual plants, and thus there was no comparison between fascicles from the population.

Some species have more variation within the population, and some morphological characteristics are more variable than others (table 4.5.1.1). *Sphagnum wulfianum* has the least amount of variation within the population. Variation among the individuals of *S. wulfianum* was found in the characteristics of the leaf tip. *Sphagnum fuscum* has the most variation within the population.

The least variable morphological characteristics within a population are leaf width, and basal pore diameters (species that do not have basal pores were not included (table 4.5.1.1). The most variable characteristics are hyaline cell lengths in the centre and tip of the leaf, mean hyaline cell width, mean concave and convex pore diameters, and tip convex pore diameter.

Table 4.5.1.1. Summary of one-way analysis of variance results for the three individuals within the subsample. An asterisk (*) indicates a significant difference. "X" indicates there was insufficient data to make an analysis. "0" indicates that the species did not have that characteristic in any of the three samples. "nn" indicates the data set of at least one individual was not normal, "uv" indicates the variances among the individuals were not equal. In either case, an ANOVA was not performed. A blank space indicates an ANOVA was performed, and no significant difference was found.

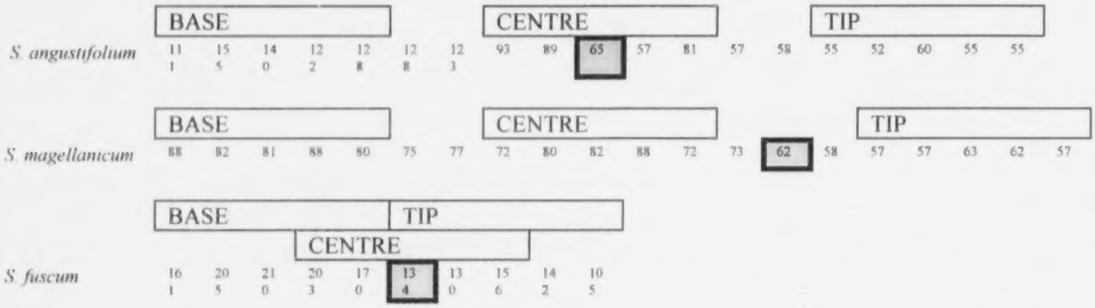
	Leaf characters			Hyaline cell characters					Concave Pore Diameter				Convex Pore Diameter			
Species	LL	LW	LC	CL-b	CL-c	CL-t	CL-m	CW	PD-b	PD-c	PD-t	PD-m	PD-b	PD-c	PD-t	PD-m
S. imbricatum	*	X	*		*		nn	nn	X	X	X	*		*		nn
S. magellanicum	nn		X	*	*	uv/nn	*	*	0	X	X				*	nn
S. papillosum	*		X	uv	*	uv	nn/uv	nn/uv	X	0	0				uv/nn	
S. angustifolium	uv	X	*	*		nn			X	X	0	X	X	X	X	uv
S. cuspidatum		X	nn	*	*		nn	nn	0	0	0	0	X	X	X	X
S. fallax	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. jensenii	*	*	X		*		*		nn	nn	X		nn	nn/uv	nn	nn
S. lindbergii	*			*	uv/nn	*		*			*	*	*		*	*
S. majus			*		uv	*		*	0	0	0	0	X	*	*	nn
S. pulchrum	*		X		nn			*	nn	*	nn	*	X	nn	nn	nn
S. riparium -em	uv	X	*		*			*	nn	*	*	*	X	X	X	nn
S. riparium - sub	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. fuscum	*		*	*	*	*		*	X	0	X	X		*	*	nn
S. girgensohnii	uv	*		*	*			*	X	X		*		*	uv/nn	nn
S. rubellum	*	X	uv	*		nn	*	*	X	X	X	X	X		*	nn
S. squarrosum		X	X	*	*	*	*		X	*	nn	*	*	uv	X	*
S. wulfianum			nn			*	nn/uv	nn/uv	X	X	X		X	uv	*	nn

Parts of the Leaf

For most morphological characteristics, the highest variation is in the centre of the leaf, then the tip of the leaf. The basal part of the leaf is the least variable between individuals within a population.

Cells in the tip of the leaf are shorter than the cells in the base of the leaf. "Centre" measurements are not necessarily positionally in the exact centre of the leaf, rather they are the five cells in the middle of the cell length data set. The transition zone between "tip-type cells" and "basal-type cells" is near the centre of the leaf, often in the upper one third of the leaf. In some species, there is an abrupt change in size between tip, while in other species the change in size is more gradual (data not shown). Centre measurements may overlap these two cell types, depending on where the transition zone is, and how large the leaf is. A sample of raw data for hyaline cell illustrates this point (table 4.5.1.2). In *S. angustifolium*, the transition zone overlaps with the "centre" data. Thus, the centre data is a combination of long and short cells. In *S. magellanicum*, "centre" cells are actually similar to basal cells. In a small leaf, such as is found in *S. fuscum*, the centre cells are actually already represented in basal and tip measurements. In a leaf one-third larger, this would not be the case. Thus, leaf size will influence centre data. Therefore, centre data is the least useful and most variable, statistically speaking. In the tip of the leaf, cell position is always the same. However, cells in the tip are often irregular in shape, especially as compared to cells in other parts of the leaf. In the tip of the leaf, resorption of hyaline cell walls occurs in some species, especially species of Section *Sphagnum*. This can distort the pore diameter information. This is the reason that tip convex pore diameters have a high degree of variation. Basal cell data are always from the first five cells starting from the base of the leaf. There is never any variability as to position of the leaf, and thus this is the most useful data for determining variation within the population.

Table 4.5.2.1: Sample of raw data for hyaline cell length, in "eye-piece units" using the 100X objective. Those cells that are used for "tip", "centre" and "base" of leaf measurements are indicated. The cell that is the first in the transition zone between basal and tip cells is also indicated.



	BASE	BASE	BASE	BASE	BASE			CENTRE	CENTRE	CENTRE	CENTRE	CENTRE			TIP	TIP	TIP	TIP	TIP	
S. angustifolium	111	155	140	122	128	128	123	93	89	**65**	57	81	57	58	55	52	60	55	55	

	BASE	BASE	BASE	BASE	BASE			CENTRE	CENTRE	CENTRE	CENTRE	CENTRE				TIP	TIP	TIP	TIP	TIP
S. magellanicum	88	82	81	88	80	75	77	72	80	82	88	72	73	**62**	58	57	57	63	62	57

	BASE	BASE	BASE	BASE	BASE	TIP	TIP	TIP	TIP	TIP
				CENTRE	CENTRE	CENTRE	CENTRE	CENTRE		
S. fuscum	161	205	210	203	170	**134**	130	156	142	105

Hanging Branch Leaf Morphology Vs Spreading Branch Leaf Morphology

Hanging branch leaves are smaller and narrower than spreading branch leaves. For most species, hyaline cells have a similar length and width. Pore morphology is different between hanging and spreading branch leaves in some species. If pore size is different, the hanging branch pores are usually larger than the spreading branch pores. This may be a functional differentiation between spreading and hanging branch leaves in some species. In some species, hanging branch leaves may have a greater role in wicking water upwards, while spreading branch leaves may have a greater role in photosynthesis. There is no data that confirm this, and it warrants further study.

Effects Of Habitat On Morphology

The differentiation between spreading and hanging branch leaves may be related to habitat, since the differentiation was greatest in the species with (presumably) the most water stress; *S. wulfianum* (a forest species). In this species, individual capitula are raised above the mat of *Sphagnum*, rather than having all of the capitula at approximately the same level as in most other species. This may be to elevate the capitula above litter from the forest trees. Movement of water into the growing capitula of the plant is thus more difficult in this species than in species that form a dense hummock. The morphology of the hanging branch leaves, presumably modified for efficient wicking, are superficially similar in appearance to the leaves of *S. fuscum*, a hummock species. *Sphagnum wulfianum* has more hanging branches than any other species (as illustrated in Crum, 1984). The numerous long, slender branches have a function similar to that of a hummock. Water can travel between the branches of the individual plant, just as it does between the branches of adjacent plants in a hummock species.

The spreading branch leaves are unique, and are presumably modified for water retention. The pores in the hanging branches of *S. wulfianum* are three to four times the size of those in the spreading branches. Thus, large hyaline cell pores are probably important in wicking, and small pores are probably important in water retention.

Leaf Shape

In *Sphagnum*, if there is a difference in shape between wet and dry leaves, dry leaves are usually more reflexed than wet leaves. Fibril frequency is higher in the tip of the leaf than other parts of the leaf. Fibril frequency may be important in preventing leaf damage due to desiccation, and the subsequent change in shape of the leaf. This is most evident in species that are subject to a varying water supply, such as species of Sections *Cuspidata*, *Polyclada* and *Squarrosa*. For instance, in *S. wulfianum* and *S. squarrosum*, as the wet capitulum dries, the spreading branch leaves become obviously more reflexed than the wet leaves (personal observation). In these species, flexion may be a defense mechanism to limit water movement. The tip of the branch initially dries out. Water will move from a wet area to a drier area. A reflexed leaf will interrupt the continuous column, and may prevent water movement to the tip, where it would only be lost to the atmosphere. Highly desiccated leaves are hydrophobic, which would further prevent water movement from the hydrated part of the plant into the desiccated part of the plant, until precipitation inundates the plant. This represents a combination of a desiccation tolerance and a desiccation avoidance strategy. The desiccated portion must tolerate that state, while the non-desiccated portion prevents desiccation.

Leaf shape may be important in water relations. Hummock species (Sections *Sphagnum* and *Acutifolia*) have leaves with blunt tips, as compared to the acute tips of species in Sections *Cuspidata*, *Squarrosa* and *Polyclada*. A blunt-tipped leaf is less able to "reflex", and thus a hummock species with blunt-tipped leaves would be less able to break the continuity of the water film by reflexing leaves than an acute-tipped leaf species. Figure 4.4.2.9 shows examples of species with blunt leaf tips (*S. magellanicum*) and species with leaf tips that have the ability to reflex (*S. squarrosum*).

4.5.2 Summary of Morphological Characteristics

LEAF SIZE

- Non juvenile leaves of *Sphagnum* are generally greater than 0.75 mm, and less than 3 mm in length. Leaf length is not related to subgeneric Sections of *Sphagnum*. Hanging branch leaves are shorter than spreading branch leaves.

- Leaf width varies from about 0.25 mm to 1.25 mm. Species in Sections *Polyclada*, *Acutifolia* and *Cuspidata* have narrower leaves than species in Sections *Sphagnum* and *Squarrosa*.

- Leaf curvature varies from 0.1 mm to 0.75 millimetres. Species of Section *Sphagnum* have the greatest leaf curvature.

HYALINE CELL SIZE

- Hyaline cell lengths vary from less than 48 µm (tip cells of *S. rubellum*) to more than 180 µm (basal cells of *S. squarrosum*), and cell widths range from 13 µm (*S. wulfianum*) to 27 µm (*S. papillosum*).

- Basal cells are the longest, tip cells are the shortest.

- Hyaline cell length is not related to subgeneric divisions in *Sphagnum*, but hyaline cell width is. Species in Sections *Polyclada* and *Cuspidata* have the most narrow cells, and species in Sections *Sphagnum* and Squarrosum have the widest cells.

PORE DIAMETER

- Pore diameters range from less than 4 µm (*S. wulfianum* concave tip pores) to more than 20 µm (*S. squarrosum* and *S. fuscum* basal pores on both sides of the leaf).

- Pores are largest at the base of the leaf, and smallest at the tip.

- Pore diameter is related to subgeneric Sections of *Sphagnum*. Sections *Sphagnum*, *Acutifolia* and Squarrosum have the largest pores, and Sections *Polyclada* and *Cuspidata*.

PORE FREQUENCY AND PORE AREA

- Most of the pores (and pore area) in species of the *Cuspidata* are on the concave side of the leaf, except in *S. majus*, where the pores are on the convex side of the leaf. Pore area and pore frequency is greater on the convex side of the leaf in species of Sections *Acutifolia*, *Sphagnum*, *Squarrosa* and *Polyclada*.

- Pore frequencies are lowest in the basal portion of the leaf, and highest in the tip of the leaf.

- In species of Section *Sphagnum*, *Polyclada* and *Acutifolia* (except *S. girgensohnii*), concave pore area is greatest on the edge of the leaf. In species of Sections *Squarrosa* and *Cuspidata*, and *S. girgensohnii*, pore area is greatest at the tip of the leaf.

- Convex pore area is greatest in the basal part of the leaf in species of Sections *Acutifolia* and *Squarrosa*, and greatest in the tip of the leaf in species of Sections *Sphagnum*, *Polyclada* and *Cuspidata*.

- Pore Frequency and concave pore area are not related to subgeneric sections of *Sphagnum*, but convex pore area is. Species in Sections *Acutifolia* and *Sphagnum* have the highest convex pore area, and species in Section *Cuspidata* have the lowest.

FIBRIL FREQUENCY

- The variation coefficient is smaller for fibril frequency than any other morphological characteristic.

- Fibril frequency ranges from about 17 fibrils per 105 µm (basal fibrils in *S. girgensohnii*, to 36 fibrils per 105 µm in the tip of *S. cuspidatum* leaves.

- Species in Section *Cuspidata* have the highest fibril frequencies. Species in Sections *Acutifolia* and *Sphagnum* have the lowest fibril frequencies.

- Fibril frequency may be related to the habitat of a species. *Sphagnum cuspidatum* and *S. majus*, both submerged species, have the most fibrils. However, within a single species (*S. riparium*) habitat does not affect fibril frequency, except in the tip of the leaf (submergent *S. riparium* has fewer fibrils than emergent *S. riparium*).

- Fibril frequency is lowest at the base of the leaf and highest at the tip of the leaf. This may be related to pore size, as basal pores are larger than tip pores.

HANGING BRANCH LEAF MORPHOLOGY COMPARED TO SPREADING BRANCH LEAF MORPHOLOGY

- Hanging branch leaves are narrower, and shorter than spreading branch leaves.

- Hyaline cells are the same size in hanging and spreading branch leaves.

- Pores are generally larger and pore area is greater in hanging branch leaves than spreading branch leaves.

- Pores do not necessarily follow the same distribution pattern (number of pores per cell) in the hanging branch leaves as in the spreading branch leaves. This is true in *S. angustifolium*, *S. lindbergii*, *S. fuscum*, *S. papillosum*, *S. squarrosum*, and *S. wulfianum*. For example, in *S. papillosum*, there are no pores on the concave side in spreading branch leaves, but there are central and tip pores on the concave side of the hanging branch leaves. Differing pore patterns in spreading and hanging branch leaves may be an indication of functional differentiation.

- Degrees of differentiation between spreading and hanging branch leaf morphology may be related to growth habit and habitat, and how they relate to water movement and availability. For instance, *S. wulfianum*, a forest species has the greatest amount of differentiation, and it probably has the highest degree of water stress (especially in the spreading branch leaves, since there are no neighbouring plants touching the capitulum, as in a hummock species. *Sphagnum magellanicum*, a hummock species, has the lowest amount of differentiation. In this species, all the leaves (hanging and spreading) are probably needed for upward movement of water.

- In most species, the largest pores are found on the convex side of the hanging branch leaves, and the smallest pores are found on the concave or convex side of the spreading branch leaf.

- On the concave side of the leaf, pore area is greater in hanging branch leaves than spreading branch leaves. Pore area distribution patterns are similar, except in species of Section *Sphagnum* (tip pore area is several times greater in hanging branch leaves than spreading branch leaves).

- On the convex side of the leaf, all species have a greater pore area in hanging branch leaves than spreading branch leaves. Pores are more evenly distributed in all parts of the leaf in hanging branch leaves than spreading branch leaves.

- Except in *S. squarrosum* and *S. wulfianum*, fibril frequencies are the same in hanging branch leaves and spreading branch leaves. In *S. wulfianum*, lower fibril frequency in hanging branches is probably related to larger pore size.

Chapter 5: Comparison Between Calendered and Uncalendered Board

5.1 Introduction

Characteristics of the leaf cells, such as pore size, are not affected by calendering. Calendering will affect gross leaf characteristics. The total volume of water a leaf can hold will be changed if the leaf does not regain its original shape upon rehydration after calendering. The difference in volume will depend on the extent and type of damage the leaf incurs. My hypothesis is that larger leaves and leaves with higher curvatures are more susceptible to calendering damage.

In this experiment, the effect of calendering on the degree to which the leaves are able to regain their original curvature is measured. The importance of size (length and width) and curvature in determining whether or not the leaf remains undamaged after calendering is also determined. The extent of the damage in each species is measured. The effects of calendering in the commercial board on members of Sections *Sphagnum*, *Acutifolia* and *Cuspidata* is also determined. The commercial board breakage results are compared to the monospecific results in each section.

5.2 Materials and Methods

Leaves from a sample of board were placed on a glass microscope slide. From each sample, ten unbroken leaves (the first ten encountered) were measured for leaf length, width and curvature using the same methods as described in chapter 4. The slide was then moved around at random, and the leaf closest to the centre of the viewing area was scored for degree of breakage. Measurements were taken from samples of calendered board, and a board which has not been calendered (uncalendered board) of *S. angustifolium, S. cuspidatum, S. fallax, S. magellanicum, S. majus, S. papillosum, S. pulchrum* and *S. rubellum*. In addition, leaf breakage data from calendered boards of *S. lindbergii, S. riparium, S. girgensohnii* and *S. imbricatum* were taken for comparison (no uncalendered boards were available). Commercial board samples (calendered and uncalendered) were also examined for breakage, except the sample size was 50 leaves instead of twenty, and the results for leaves from different taxonomic Sections

(*Sphagnum*, *Acutifolia* and *Cuspidata*) were separated. Morphological and breakage measurements were made from hanging and spreading branch leaves of *S. wulfianum* (calendered board). This is the only species where the two types of leaves can be differentiated with certainty in a board sample.

Damage

Degrees of damage were given a numerical score. "Ten" is a perfect leaf with no tears, holes or splits. "9" is a leaf with slight damage (often a split in the basal region). Scores of 7.5, 5, and 2.5 were given to leaves where the fragment was approximately three quarters, half and one quarter the estimated size of the original leaf. A score of one was given to a fragment that was at least one tenth the size of the original leaf but less than one quarter. Smaller fragments were ignored. The most prevalent types of damage (breakage along the length or along the width of the leaf, or leaf splitting in the basal region) were noted for each species. The percentage of leaves measured that had a basal split and no other damage was recorded.

A one way ANOVA was used to test for significant differences in leaf size characteristics (length, width, and curvature) of unbroken leaves in calendered and uncalendered board. Where data was not normal or had an unequal variance between the two samples, the ANOVA analysis was omitted. Normality and homogeneity of variance were tested using SPSS (Lilliefors and Levene statistics, respectively), and results are found in Appendix 4. Degree of leaf breakage is compared between calendered and uncalendered boards (all data was skewed, and could not be compared using an ANOVA). Unbroken leaves of significantly different sizes between calendered and uncalendered board indicates that leaf size is important in the statistical probability of a particular leaf being damaged during calendering. A significant difference between leaf breakage of calendered and uncalendered board indicates that damaged is caused during the calendering process. No significant difference indicates that damage occurred before calendering.

SEM Analysis

Calendered and uncalendered boards of *Sphagnum* were examined using a Cambridge S250 scanning electron microscope (SEM). Calendered and uncalendered boards made from monospecific samples of *Sphagnum angustifolium, S. cuspidatum, S. fallax, S. fuscum, S. magellanicum, S. pulchrum, S. papillosum,* and *S. rubellum,* and a typical commercial board were examined.

A small piece of board, about 0.25 cm^2, was cut about 5 cm from the edge of the board. The fragment was gently torn in half, exposing the inside of the board. The piece was attached to an SEM stub, gold coated to a thickness of 150 Angstroms, and examined. Another sample was placed in liquid nitrogen and freeze-fractured, and then freeze-dried and attached to an SEM stub with double-sided carbon tape.

5.3 Results

5.3.1 Leaf Size

The length and width of a *Sphagnum* leaf does not affect the probability of that leaf being broken during the calendering process (tables 5.3.1.1 and 5.3.1.2). However, the mean size of unbroken leaves in board is smaller than in the fresh moss from which the board was made. Thus, small leaves are less likely to be damaged *before calendering* than large leaves (figures 5.3.1.1 and 5.3.1.2 compared to 4.3.1.1 and 4.3.1.2). This is true for all species except for *S. rubellum*, which has the smallest leaves out of all of those measured for breakage (less than 1 mm in length).

Sphagnum magellanicum has the greatest difference between leaf size of fresh moss and undamaged board leaves. Fresh moss leaves are nearly 40% larger in length and width than *S. magellanicum* board leaves. Conversely, in *S. papillosum*, which has larger leaves than *S. magellanicum*, undamaged board leaves are only 12% shorter than the mean of fresh leaves, but are nearly twice as narrow. Therefore, in species of Section *Sphagnum*, it is not the necessarily the length of a leaf that results in damage, but the width (and curvature, which is related to the width).

The mean leaf length for all species of fresh moss is 1.5 mm, while the mean length for board leaves is less than 1.2 mm. Mean leaf width for fresh moss is 560 micrometers, and 375 micrometers for board leaves. Leaves that at 1.2 mm or less in length, and 0.375 mm or less in width are the least likely to be broken during processing.

5.3.2 Leaf Curvature

There is no reduction in potential leaf curvature due to calendering (table 5.3.2.1). Unbroken leaves in calendered *Sphagnum* board, upon rehydration, have the same curvature as those in calendered board.

Leaf damage due to processing before calendering is related to a high leaf curvature in species of Section *Sphagnum*. In *S. papillosum*, the curvature of unbroken board leaves is less than half that of fresh moss (figure 5.3.2.1 and 4.3.1.3). This may mean either that processing reduces leaf curvature in *Sphagnum*, or that leaves with high curvatures are more likely to be broken during processing. Evidence for the latter is that in four species (*S. angustifolium, S. cuspidatum, S. majus* and *S. rubellum*) there is less than a 20 micrometer difference between curvature of the board leaves and of the fresh moss leaves. In *S. cuspidatum* and *S. majus*, two species with low curvatures, the difference in curvature between board leaves and fresh moss leaves is less than 7 micrometers. In species with low curvatures, curvature does is not related to leaf breakage.

5.3.3 Leaf Breakage

Commercial Board

In commercial *Sphagnum* board, there are differences in the degree of leaf breakage between calendered board and uncalendered in species from Section *Sphagnum*, but not in leaves of species in Sections *Acutifolia* or *Cuspidata* (figure 5.3.3.1). (No leaves of species in other taxonomic Sections were found in the board samples). Thus, calendering is probably not responsible for leaf breakage in Sections *Cuspidata* and *Acutifolia*, while in Section *Sphagnum* calendering does cause some breakage. The leaves in the commercial board sample were mostly from species in Section *Cuspidata* (>80%); about 15% from Section *Sphagnum*; and the remainder from Section *Acutifolia*.

A. TAXONOMIC GROUPS

Leaves of species in Section *Sphagnum* are the most fragmented, both in commercial board and in monospecific board. In this group, the average leaf fragment in calendered board is approximately half the size of the original leaf. In species of Sections *Acutifolia* and *Cuspidata*, calendered leaves are usually more than 80% the size of the original leaf in monospecific board. In commercial board, Section *Acutifolia* leaves (probably *S. rubellum*) were virtually undamaged, and species in Section *Cuspidata* scored about 8.5 (some damage).

B. TYPE OF DAMAGE

Different types of leaf breakage are seen among the taxonomic groups. Fragmented leaves are most common in species of Section *Sphagnum*. It was often difficult to find unbroken leaves in this group, especially in the calendered samples. In less damaged leaves, breakage was across the width, often on a diagonal axis. Breakage initially occurs between shorter cells in the upper one third of the leaf. Leaves where basal splitting is the only damage are rarely found in this group.

In the species of Section *Acutifolia*, breakage usually occurs across the width of the leaf, similar to Section *Sphagnum*. However, fragmentation was not common, probably because the leaves of species in this group are much smaller than those of species in Section *Sphagnum*. Otherwise unbroken leaves with basal splitting are found, but are not common.

In species of Section *Cuspidata*, basal splitting as the only damage was commonly found. Breakage usually occurs along the length of the leaf, either in the center beginning from the base, or one third of the way in from the edge, again beginning from the base. This is probably the area where the leaf was "creased" during calendering. In *S. cuspidatum*, broken tips were also common. Calendering causes basal splitting in *S. majus* and *S. pulchrum* (table 5.3.3.1).

The type of damage that occurs is likely related to hyaline cell size and shape. Cells in species in the Section *Cuspidata* are narrow and straight in comparison to those species in Sections *Sphagnum* and *Acutifolia*. Position of the chlorophyllous cell in relation to the hyaline cell may be important. In species of Section *Cuspidata*, the chlorophyllous cells are extruded on the convex surface, while in species of Section *Acutifolia*, they are extruded on the concave surface (as seen in Crum, 1984).

C. HANGING VS SPREADING BRANCH LEAVES

In calendered boards manufactured from *S. wulfianum*, there was no significant difference between the degree of damage in the hanging branch leaves and the spreading branch leaves. However, damage may have been prevented by the size of the leaf, as this species has relatively small leaves in both the spreading and the hanging branches. The spreading branch leaves, which have narrower hyaline cells (figure 4.4.2.2) than hanging branch leaves, have a higher incidence of basal splitting than do spreading branch leaves. This, in combination with the low incidence of this type of damage in Sections *Sphagnum* and *Acutifolia* and the high incidence in Section *Cuspidata*, may be evidence that wide hyaline cells help prevent basal splitting. In this species, the chlorophyllous cells are centrally located and not extruded on either surface in both leaf types.

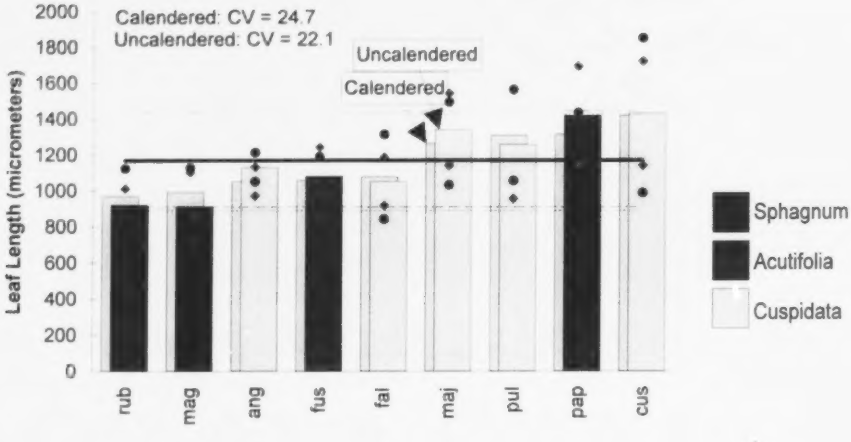


Figure 5.3.1.1: Comparison of leaf lengths (micrometers) of unbroken leaves in calendered (background) and uncalendered (foreground) board made from *S. angustifolium, cuspidatum, fallax, fuscum, magellanicum, majus, papillosum, pulchrum,* and *rubellum*.. Circles are one standard deviation from individual uncalendered board means, diamonds are one standard deviation from individual calendered board means.

Table 5.3.1.1: Comparison of lengths of unbroken leaves in calendered and uncalendered board. F, P and F Critical values are included. N is 10 for each board sample. Shading indicates a significant difference between unbroken leaf lengths in calendered and uncalendered samples.

Species	*Board*	*Mean Leaf Length (μm)*	*Std Dev*	*F*	*P-value*	*F crit*
S. angustifolium	Calendered	1051.62	80.52	5.86	0.0262	8.29
	Uncalendered	1131.18	65.66			
S. cuspidatum	Calendered	1430.04	290.13	0.01	0.9415	4.41
	Uncalendered	1417.80	431.28			
S. fallax	Calendered	1051.62	134.84	unequal variances		
	Uncalendered	1078.14	235.66			
S. fuscum	Calendered	1081.20	160.92	0.14	0.7155	4.41
	Uncalendered	1056.72	133.44			
S. magellanicum	Calendered	912.90	187.91	1.22	0.2846	4.41
	Uncalendered	993.48	134.39			
S. majus	Calendered	1341.30	201.22	0.66	0.4274	4.41
	Uncalendered	1262.76	230.34			
S. papillosum	Calendered	1417.80	274.96	unequal variances		
	Uncalendered	1313.76	120.19			
S. pulchrum	Calendered	1258.00	302.01	0.15	0.7048	4.49
	Uncalendered	1309.00	253.81			
S. rubellum	Calendered	921.06	88.80	unequal variances		
	Uncalendered	971.04	154.45			

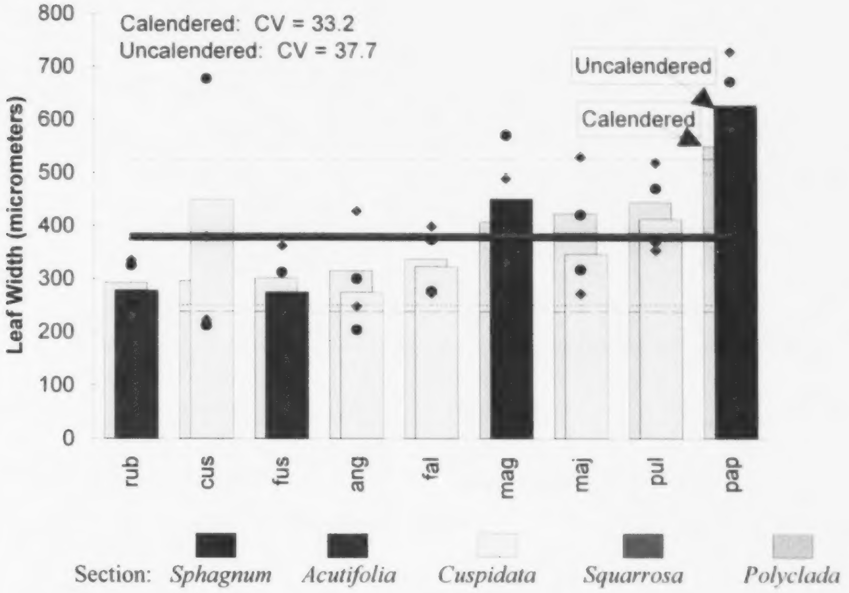


Figure 5.3.1.2: Comparison of leaf widths (micrometers) of unbroken leaves in calendered (background) and uncalendered (foreground) board made from *S. angustifolium, cuspidatum, fallax, fuscum, magellanicum, majus, papillosum, pulchrum,* and *rubellum.*. Circles are one standard deviation from individual uncalendered board means, diamonds are one standard deviation from individual calendered board means.

Table 5.3.1.2: Comparison of widths of unbroken leaves in calendered and uncalendered board. F, P and F Critical values are included. N is 10 for each board sample.

Species	*Board*	*Mean Leaf Width (μm)*	*Std Dev*	*F*	*P-value*	*F crit*
S. angustifolium	Calendered	315.18	111.47	data not normal		
	Uncalendered	274.38	26.09			
S. cuspidatum	Calendered	295.80	84.11	4.03	0.0598	4.41
	Uncalendered	449.82	227.44			
S. fallax	Calendered	337.62	60.91	data not normal		
	Uncalendered	323.34	49.98			
S. fuscum	Calendered	301.92	60.67	1.39	0.2531	4.41
	Uncalendered	275.40	36.93			
S. magellanicum	Calendered	408.00	81.17	0.88	0.3613	4.41
	Uncalendered	450.84	119.71			
S. majus	Calendered	423.30	106.14	3.47	0.0789	4.41
	Uncalendered	346.80	74.80			
S. papillosum	Calendered	550.80	177.26	unequal variances		
	Uncalendered	628.32	44.38			
S. pulchrum	Calendered	445.40	73.94	1.00	0.3330	4.49
	Uncalendered	412.53	58.34			
S. rubellum	Calendered	292.74	42.48	0.51	0.4832	4.41
	Uncalendered	278.46	46.63			

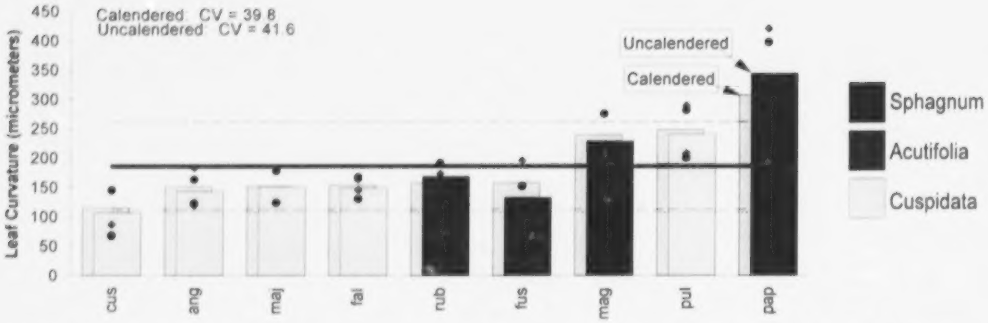


Figure 5.3.2.1: Comparison of leaf curvature (micrometers) of unbroken leaves in calendered (background) and uncalendered (foreground) board made from *S. angustifolium, cuspidatum, fallax, fuscum, magellanicum, majus, papillosum, pulchrum,* and *rubellum*.. Circles are one standard deviation from individual uncalendered board means, diamonds are one standard deviation from individual calendered board means.

Table 5.3.2.1: Comparison of curvature of unbroken leaves in calendered and uncalendered board. F, P and F Critical values for each species are included. N is 10 for each board sample.

Species	*Board*	*Mean Leaf Curvature (μm)*	*Std Dev*	*F*	*P-value*	*F crit*
S. angustifolium	Calendered	151.09	31.55	0.46	0.5078	8.29
	Uncalendered	143.07	20.41			
S. cuspidatum	Calendered	115.33	28.75	0.33	0.5705	4.41
	Uncalendered	106.57	38.35			
S. fallax	Calendered	154.01	8.74		data not normal / unequal variances	
	Uncalendered	148.91	18.59			
S. fuscum	Calendered	157.66	36.93	3.59	0.0744	4.41
	Uncalendered	132.85	18.78			
S. magellanicum	Calendered	239.42	35.89	0.35	0.5612	4.41
	Uncalendered	228.47	46.17			
S. majus	Calendered	151.82	27.70	0.01	0.9058	4.41
	Uncalendered	150.36	26.70			
S. papillosum	Calendered	306.57	113.08		unequal variances	
	Uncalendered	343.07	52.97			
S. pulchrum	Calendered	248.18	40.39		data not normal	
	Uncalendered	240.06	40.60			
S. rubellum	Calendered	157.66	15.08	1.70	0.2091	4.41
	Uncalendered	168.61	21.88			

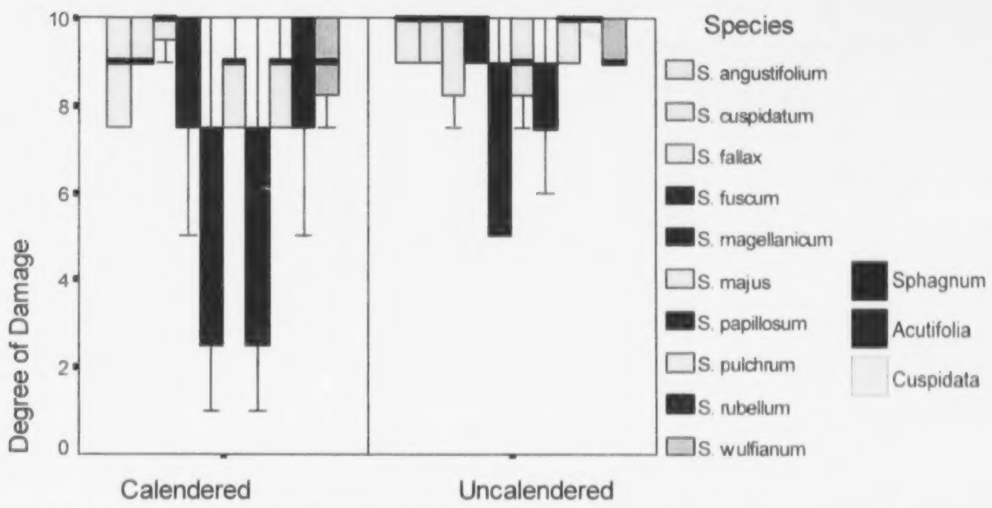


Figure 5.3.3.1: Comparison of leaf breakage of leaves in calendered and uncalendered board. Leaves were scored on a scale of one to ten, with "10" an undamaged leaf and "1" a leaf fragment. Species are in same order as they appear in the legend.

Table 5.3.3.1: Comparison of leaf breakage in calendered and uncalendered board. N is 20 for each monospecific board sample. N totals 50 for commercial samples. "HB" = hanging branch leaf; "SB" = spreading branch leaf. "% split" is the percentage where the only damage present was a basal split.

Species	*Board*	*Leaf Breakage Factor*	*Std Dev*	*% Split*
Commercial Board	Calendered	7.15	2.90	18%
Section *Cuspidata*	Uncalendered	8.48	2.39	20%
Commercial Board	Calendered	9.00	0.00	0%
Section *Acutifolia*	Uncalendered	9.25	1.42	7%
Commercial Board	Calendered	3.21	2.44	0%
Section *Sphagnum*	Uncalendered	7.59	2.84	9%
S. angustifolium	Calendered	9.00	1.09	0%
	Uncalendered	9.58	0.67	0%
S. cuspidatum	Calendered	8.79	1.71	5%
	Uncalendered	9.05	1.56	10%
S. fallax	Calendered	9.53	1.17	0%
	Uncalendered	8.92	1.66	10%
S. fuscum	Calendered	8.28	2.28	5%
	Uncalendered	9.57	0.66	0%
S. magellanicum	Calendered	5.50	3.12	0%
	Uncalendered	7.12	2.21	0%
S. majus	Calendered	8.61	1.25	25%
	Uncalendered	8.89	1.06	15%
S. papillosum	Calendered	4.68	3.00	0%
	Uncalendered	7.66	1.60	5%
S. pulchrum	Calendered	7.88	1.86	40%
	Uncalendered	9.02	1.31	15%
S. rubellum	Calendered	8.75	1.60	0%
	Uncalendered	9.80	0.41	0%
S. wulfianum (HB)	Calendered	8.78	1.67	5%
S. wulfianum (SB)	Uncalendered	8.60	1.88	15%

5.3.4 SEM Analysis

Calendered and uncalendered boards are compared (figure 5.3.4.1). Cells may be unchanged, compressed greatly to slightly, or wrinkled after calendering. In some cases (e.g., *S. rubellum, S. fuscum,* commercial board) some minor cell damage was noted in calendered samples.

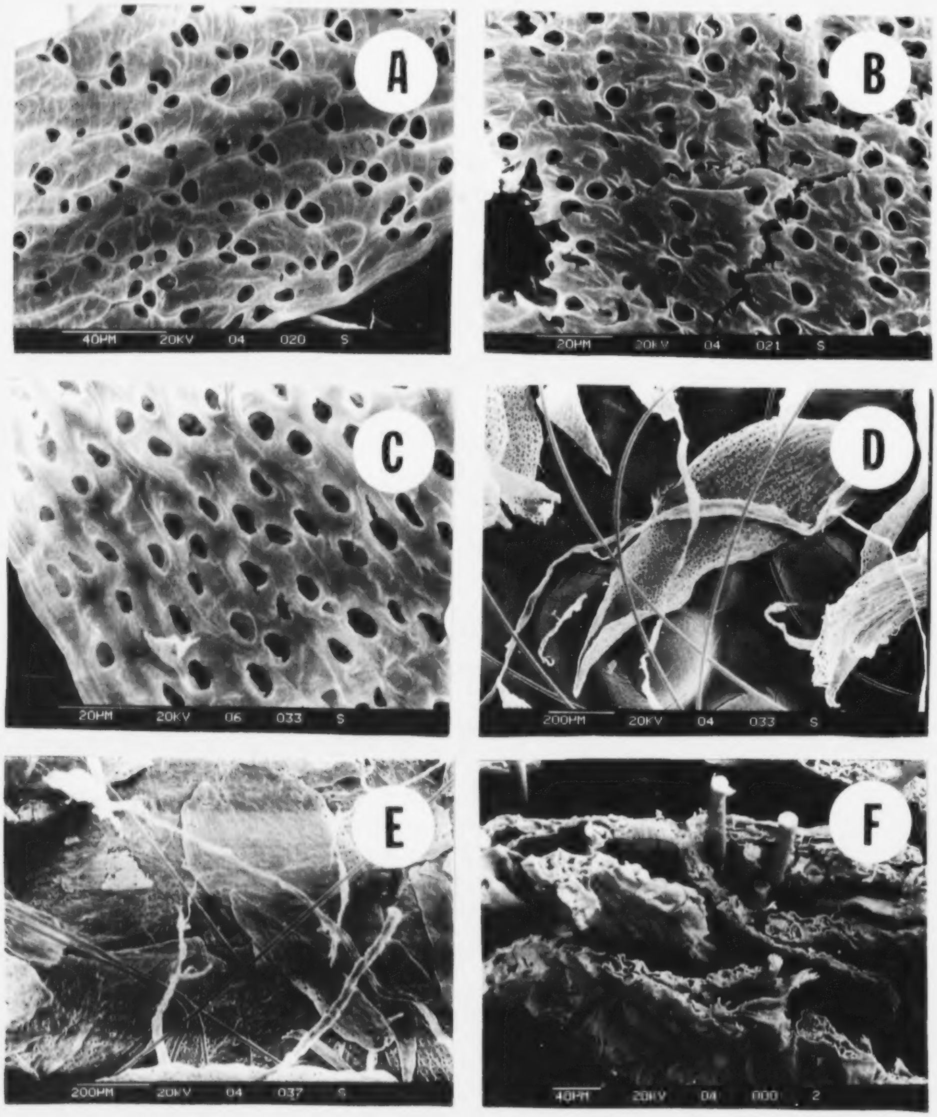
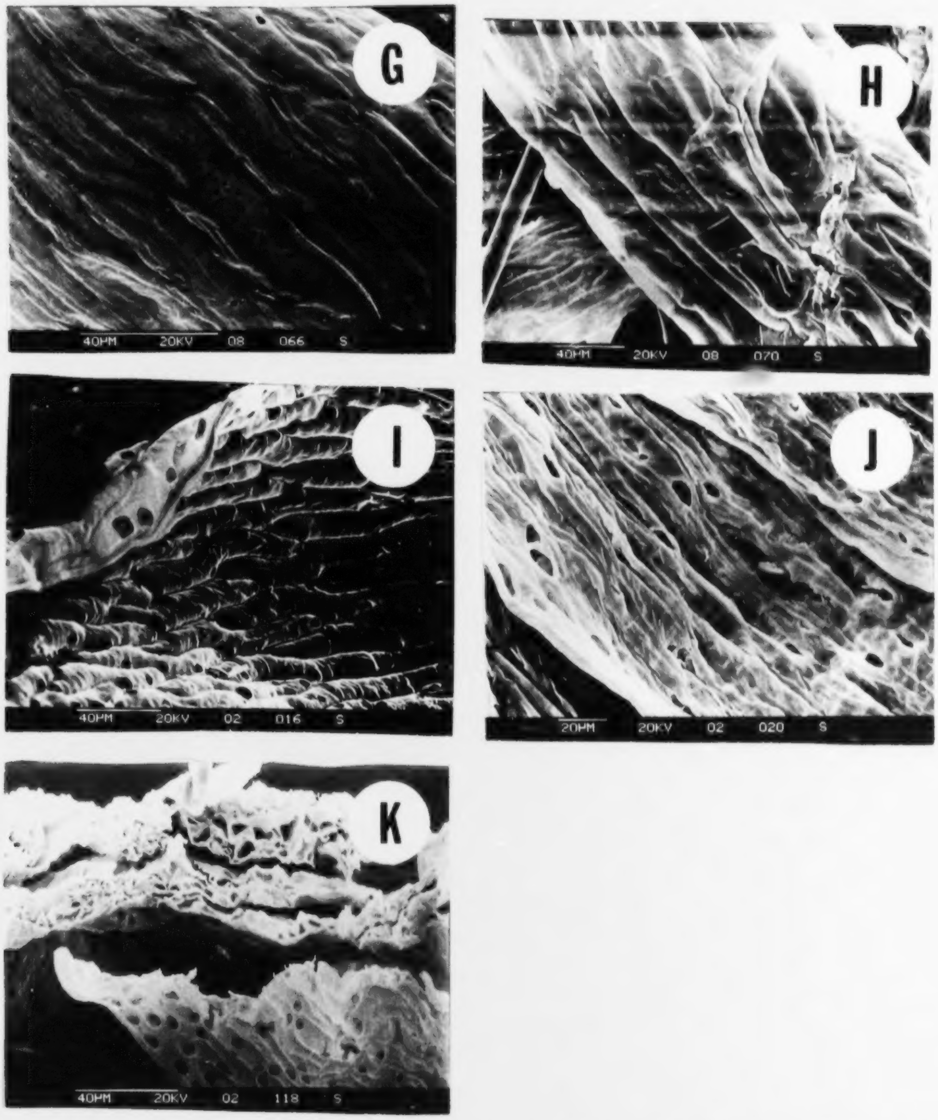
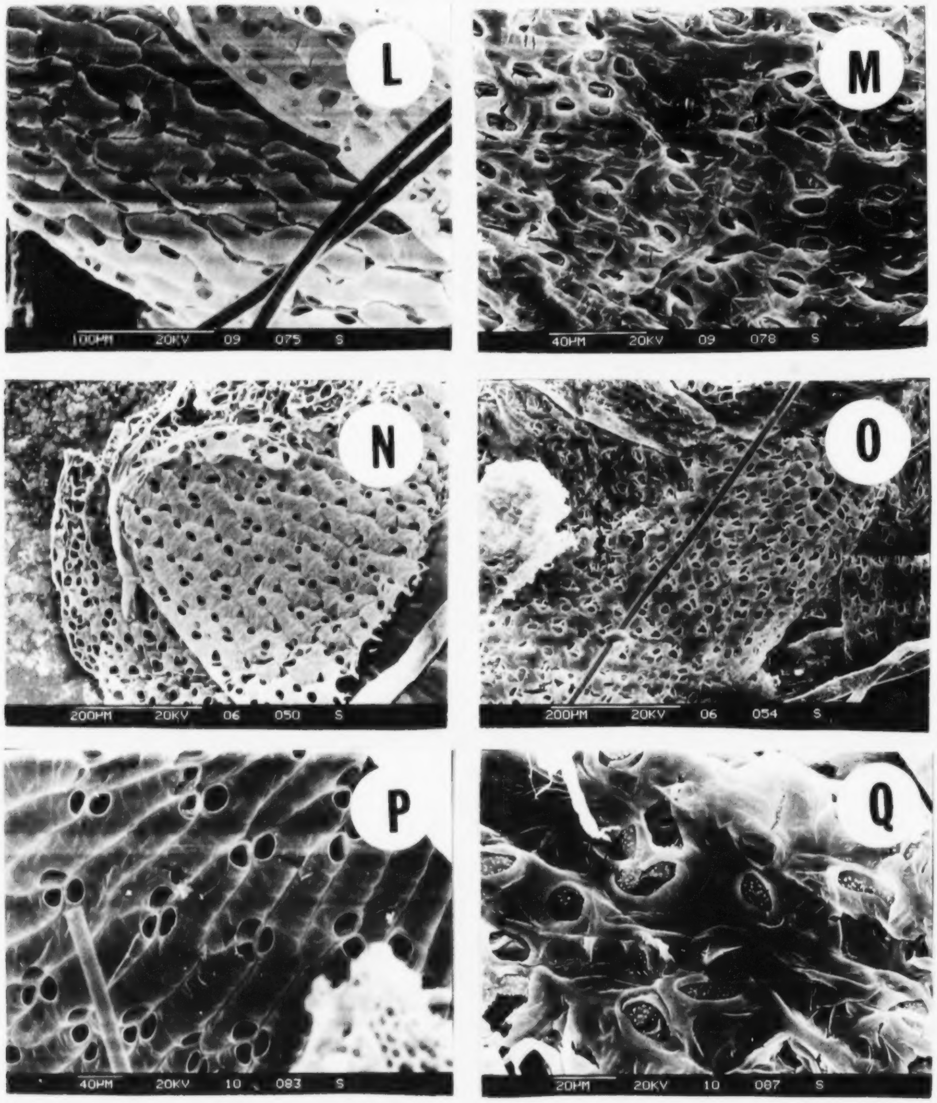

A
40HM 20KV 04 020 S
B
20HM 20KV 04 021 S
C
20HM 20KV 06 033 S
D
200HM 20KV 04 033 S
E
200HM 20KV 04 037 S
F
40HM 20KV 04 000 2

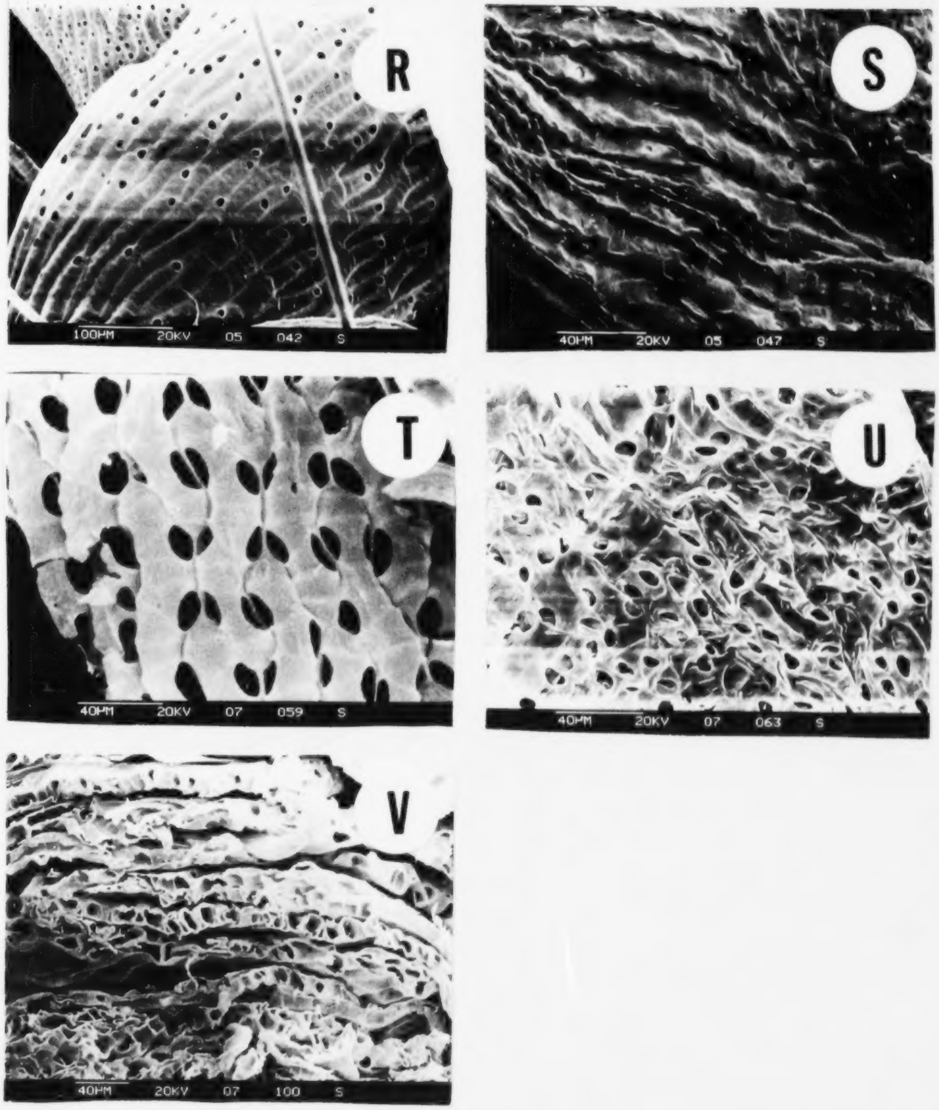
Figure 5.3.4.1: Comparison between calendered and uncalendered boards.
(a-c) Commercial board, species from Section *Sphgnum*. (a) and (b) Commercial uncalendered board compared to (c) leaf fragmant from a calenedered board. As (b) demonstrates, damage can occur before calendering. (d-f) *S. angustifolium* (d) a leaf in the uncalendered board and (e) a leaf in the calendered board. (f) Calendered freeze-fractures board showing arrangement of leaves and polyester fibres.


G
40µM 20KV 08 066 S
H
40µM 20KV 08 070 S
I
40µM 20KV 02 016 S
J
20µM 20KV 02 020 S
K
40µM 20KV 02 118 S

(g-h) *S. cuspidatum* (g) hyaline and chlorophyllous cells in an uncalendered board (h) and in calendered board. (i-k) *S. fallax* (i) undamaged hyaline cells in uncalendered board (j) undamaged but partially compressed cells in calendered board. (k) Freeze-fractured view of calendered board, exhibiting some compressed hyaline cells and some non-compressed hyaline cells.


L
M
100µM 20KV 09 075 S
40µM 20KV 09 078 S
N
O
200µM 20KV 06 050 S
200µM 20KV 06 054 S
P
Q
40µM 20KV 10 083 S
20µM 20KV 10 087 S

(l-m) *S. fuscum* (l) uncompressed hyaline cells in uncalendered board and (m) partially compressed cells in calendered board exhibiting a minimal amount of damage. (n-o) *S. magellanicum* (n) leaf fragment in uncalendered board compared to leaf fragment in calendered board (o). (p-q) *S. papillosum* (p) hyaline cells in uncalendered board exhibiting a minimal amount of damage, compared with (q) almost completely compressed hyaline cells in calendered board exhibiting a greater amount of damage. Papillae can be clearly seen in the calendered board, since the opposite side of the hyaline cell wall is in approximately the same focusing plane as the pores on this side of the cell wall.


R
100HM 20KV 05 042 S
S
40HM 20KV 05 047 S
T
40HM 20KV 07 059 S
U
40HM 20KV 07 063 S
V
40HM 20KV 07 100 S

(r-s) *S. pulchrum* (r) virtually undamaged hyaline cells in uncalendered board and (s) hyaline cells in calendered board are compressed, but have only minimal damage to the cell wall. (t-v) *S. rubellum* (t) fully exanded hyaline cells in uncalendered board with minimal damage compared to (u) slight amount of damage in compressed calendered hyaline cells. (v) Freeze-fractured view of calendered board. Not all hyaline cells are compressed, and those that are are not completely compressed.

5.4 Conclusions and Summary

- Species with small leaves are less likely to be damaged during processing prior to calendering than species with large leaves.

- Maximum leaf size to prevent breakage during processing prior to calendering is 1400 μm long, 550 μm wide, and a curvature of 300 μm.

- Calendering causes leaf breakage in *S. papillosum, S. rubellum, S. pulchrum,* and *S. fuscum*. In commercial board, calendering caused breakage in leaves from species in Section *Sphagnum*, but not Sections *Acutifolia* and *Cuspidata*.

- If a leaf is unbroken in the uncalendered board, damage (if any) due to calendering is not related to leaf size.

- In an undamaged leaf, the calendering process does not affect rehydrated leaf curvature.

- Calendering is more likely to cause damage in commercial peat than in monospecific fresh moss samples of Sections *Sphagnum* and *Cuspidata*. This may be related to decomposition weakening leaf structure in commercial peat. Leaves in commercial peat of species in Section *Acutifolia* have less damage than those in Sections *Cuspidata* and *Sphagnum*.

- Broken leaves of species in Section *Sphagnum* are usually fragmented or broken across the width of the leaf, leaves of species in Section *Acutifolia* usually break in the upper third of the leaf across the width. Leaves of species in Section *Cuspidata* usually break along the length of the leaf, beginning from the base. In species with very long leaves, they may also break at the tip.

- Leaf breakage type may be related to hyaline cell size. Wide hyaline cells may prevent lengthwise splitting.

- After calendering, hyaline cells are wrinkled, and may be compressed, but air space remains within the hyaline cell. In some cases, cells do not appear to be compressed. SEM analysis shows minor cell damage (usually small cracks) in some leaves of calendered board.

Chapter 6: Multivariate Analysis - Absorbency Vs Morphology

6.1 Introduction

In previous chapters, morphological features and absorbency characteristics of different species and treatments of *Sphagnum* are outlined. A multivariate analysis was carried out in order to determine interrelationships between morphology and absorbency.

All species of *Sphagnum* share numerous basic morphological characters; e.g.: spreading and hanging branches, general leaf shape, and presence of hyaline cells containing pores and fibrils. Morphological characteristics were measured, and the results are found in chapter four. It has long been postulated that the hyaline cells of *Sphagnum* are responsible for its absorptive abilities (Moldenhawer, 1812). However, it is currently unknown what role an individual morphological characteristic plays in absorption. The general morphology of those species that occur in pools is shared by those on hummocks. This chapter reveals which morphological characteristics are *associated* with which absorbency characteristics. Other chapters will put forward some possible models as to the *role* of morphological characteristics in absorbency. The important question to answer is, "What are the optimal morphological characters of *Sphagnum* for maximum absorbency?" In determining the optimal morphological characteristics, the best species can be identified for use in absorptive products.

Canonical Community Ordination (Ter Braak, 1988), known by the acronym of CANOCO, is a statistical tool with widespread use in ecology. The program CANOCO is a multivariate direct gradient analysis that is used to test how species respond to environmental factors. According to its developers, it can also be used in other applications, particularly, if the number of response (species) variables is large in comparison to the number of sites. Since numerous morphological features (of the leaves and the board) were measured, they are used as the response variable (pseudo-species) in CANOCO. The habitat in which the *Sphagnum* species naturally occurs is included with the morphology characters. Since the program requires that species data be input as percent cover, the morphological features are scaled. Absorbency values were entered in place of environmental variables. The species and treatments (i.e. whole plants and habitat) are entered as sites.

Multivariate statistical analyses were carried out with all species included, and by subgeneric group (Sections *Sphagnum*, *Cuspidata* and *Acutifolia*). This was in order to determine the subtle differences between similar species that are most responsible for the variation among species in absorbency.

One of the limitations of multivariate analysis is that characteristics which are similar among all species may not show up to be "important" in absorption due to this similarity. The CANOCO analysis was designed for use in ecological studies, and if a species has the same abundance in all of the plots then environment must not be a an important factor in determining where the plant grows (within the confines of the study). The same concept does not necessarily apply in our analysis. If all the species have a morphological feature that is approximately equivalent, and does not show up as being "important", this does not mean that the characteristic is not important in absorption, only that it is not important for determining the variability in absorption between the species. It could be argued that such a feature is very important, since it is common between the species. However, we cannot determine *how* such a feature is important with regards to absorbency; we can only speculate. This problem also occurs when the absorbency characteristics within a group are similar. This makes it difficult to determine which morphological feature is important for that absorbency characteristic. If a feature within a taxonomic section is identical among the species of that group, associations for that feature must be inferred from other groups that have greater variation between species because that feature will not be plotted in the CANOCO output.

6.2 Materials And Methods

6.2.1 Data Used In Ordination

Detrended **C**anonical **C**orrespondence **A**nalysis (DCCA) within the program CANOCO (Ter Braak, 1988) was used to analyze morphological, absorbency and species data. Primary input and output data are in Appendix 2. DCCA was used because in some cases curved patterns were noticed when a

Table 6.2.1.1: Species and treatments of *Sphagnum* used as site data:

S.
S. cuspidatum
S. fallax
S. fuscum
S. girgensohnii
S. imbricatum
S. lindbergii
S. magellanicum
S. majus
S. papillosum
S. pulchrum
S. riparium
S. rubellum
S. squarrosum
S. wulfianum
S. fuscum - whole plants
S. imbricatum - whole plants
S. magellanicum - whole plants
S. riparium - emergent - whole plants
S. riparium - submerged - whole

Table 6.2.1.2 Morphological characters used as "Pseudo-species".

No.	**Abbreviation**	**Morphological Characteristic**
1	LL	LEAF LENGTH
2	LW	LEAF WIDTH
3	LC	LEAF CURVATURE
4	CL-b	HYALINE CELL - LENGTH - basal
5	CL-c	HYALINE CELL - LENGTH - centre
6	CL-t	HYALINE CELL - LENGTH - tip
7	CL-a	HYALINE CELL LENGTH - mean of all
8	CW	HYALINE CELL WIDTH - LARGEST SIDE
9	PD-CC-a	PORE DIAMETER - CONCAVE - all
10	PD-CC-b	PORE DIAMETER - CONCAVE - basal
11	PD-CC-c	PORE DIAMETER - CONCAVE - middle
12	PD-CC-t	PORE DIAMETER - CONCAVE - tip
13	PD-CV-a	PORE DIAMETER - CONVEX - all
14	PD-CV-b	PORE DIAMETER - CONVEX - basal
15	PD-CV-c	PORE DIAMETER - CONVEX - centre
16	PD-CV-t	PORE DIAMETER - CONVEX - tip
17	PD-CC-a	PORE FREQUENCY - CONCAVE -mean of all
18	PF-CC-b	PORE FREQUENCY - CONCAVE - basal
19	PF-CC-c	PORE FREQUENCY - CONCAVE - centre
20	PF-CC-t	PORE FREQUENCY - CONCAVE - tip
21	PF-CV-a	PORE FREQUENCY - CONVEX -mean of all
22	PF-CV-b	PORE FREQUENCY - CONVEX - basal
23	PF-CV-c	PORE FREQUENCY - CONVEX - centre
24	PF-CV-t	PORE FREQUENCY - CONVEX - tip
25	PF-CV-E	PORE FREQUENCY - CONVEX - edge
26	PF-CC-e	PORE FREQUENCY - CONCAVE -edge
27	PA-CC-a	PORE AREA - CONCAVE - all
28	PA-CC-b	PORE AREA - CONCAVE - basal
29	PA-CC-c	PORE AREA - CONCAVE - centre
30	PA-CC-t	PORE AREA - CONCAVE - tip
31	PA-CV-a	PORE AREA - CONVEX - all
32	PA-CV-b	PORE AREA - CONVEX - basal
33	PA-CV-c	PORE AREA - CONVEX - centre
34	PA-CV-t	PORE AREA - CONVEX - tip
35	%PA-CC-a	% PORE AREA ON ONE SIDE - CONCAVE - ALL
36	%PA-CC-b	% PORE AREA ON ONE SIDE - CONCAVE - basal
37	%PA-CC-c	% PORE AREA ON ONE SIDE - CONCAVE - centre
38	%PA-CC-t	% PORE AREA ON ONE SIDE - CONCAVE - tip
39	%PA-CV-a	% PORE AREA ON ONE SIDE - CONVEX - ALL
40	%PA-CV-b	% PORE AREA ON ONE SIDE - CONVEX - basal
41	%PA-CV-c	% PORE AREA ON ONE SIDE - CONVEX - centre
42	%PA-CV-t	% PORE AREA ON ONE SIDE - CONVEX - tip
43	%PA-L	% PORE AREA ON ONE SIDE - LARGEST - ALL
44	FF-b	FIBRIL FREQUENCY - basal
45	FF-c	FIBRIL FREQUENCY - centre
46	FF-t	FIBRIL FREQUENCY - tip
47	FF-e	FIBRIL FREQUENCY - edge
48	FF-a	FIBRIL FREQUENCY - mean
49	density	BOARD DENSITY
50	dry wt	BOARD DRY WEIGHT
51	% water	% WATER CONTENT OF BOARD
52	habitat	HABITAT - WATER AVAILABILITY

Canonical Correspondence Analysis (CCA) was used, rendering this analysis less appropriate than the DCCA. The DCCA was carried out with data shown in table 6.2.1.1.

In the DCCA output, species are abbreviated using the first three letters of the specific epithet. The suffix "W" indicates the boards from which the absorbency data are measured are produced from whole plants. "Sub" and "Em" are submerged and emergent habitats, respectively.

Characters 1 to 48 were measured directly from the leaves, and are means of all values for that character in that species scaled from 0 to 100. The lowest value for a character was given a score of zero, and the highest was given a score of 100. In species that had "whole plant" as well as "leaves only" treatments, characters 1 to 48 were the same. Board characters (49, 50 and 51) were measured for the individual board samples. Habitat, character 52, was a subjective score based on the habitat in which the species was found. A score of 100% was given to species which were collected growing under water. Species were given lower scores according to the dryness of the habitat. Forest species received the lowest scores. Scores for all characters are in Appendix 2.

Table 6.2.1.3: Absorbency characteristics used in place of environmental factors.

No.	Abbreviation	Absorbency Test
1	GATS	Gravimetric Absorbency Testing System
2	DP 30	Drying Power measured after 30 minutes
3	DP 120	Drying Power measured after 120 minutes
4	RC 300g	Retention Capacity, 300g
5	RC 1200g	Retention Capacity, 1200g
6	RC Max	Maximum Retention Capacity
7	Impact	Impact

Since retention capacity is the feature that shows the largest amount of variation between species, the CANOCO was run with and without it to determine the placement of the morphological features with respect to GATS, Drying Power and Impact. When comparing the species within a taxonomic section, retention capacity was not used. If retention capacity is used, the results for other absorbency features are not clear, since retention capacity accounts for most of the variation and thus are the most important axes. Another reason for excluding it is that retention capacity is measured from the fresh moss, not the finished board. Other absorbency characteristics are measured from the board.

6.2.2 Interpretation of DCCA Results

High values for GATS, retention capacity and impact and a low value for drying power are the optimal results. The length of the eigenvectors demonstrate which variable is most (or least) responsible for variation between the species. An absorbency characteristic that plots with a long vector demonstrates that that morphological feature is responsible for more of the variation seen among the species than an absorbency characteristic with a shorter vector. If there is no eigenvector plotted, then there is no variation between the species for that absorbency characteristic. The position of the vectors in relation to the morphological features is important; the closer morphological features are positioned to a vector, the greater the probable association between that morphological feature and that absorbency characteristic.

Eigenvalues are a measure of the importance of a particular axis (Ter Braak, 1988). An eigenvalue is expressed as a number between 0 and 1; the closer it is to one, the more important that axis is in explaining the variation in the ordination. If the eigenvalue is less than 0.02, that axis is not important in the ordination (Ter Braak, 1988) as this shows that there is little variation between the species for that characteristic. The sum of the eigenvalues tells us the amount of variation that is explained by all of the data combined. If the sum of the eigenvalues is not close to one, then there are data that are not within the ordination that account for a large amount of variation. The CANOCO gives the sum of the unconstrained eigenvalues and canonical eigenvalues (constrained to be linear combinations of environmental (absorbency) variables). An optimal result would be to have the sum of the unconstrained and canonical eigenvalues approximately the same, and both near one as this would mean that the variation in absorbency among species is explained by the morphological data.

To determine the best species for a particular absorbency characteristic, a perpendicular line is drawn from the species to the eigenvector of the absorbency characteristic in question (or to a line extended from the eigenvector). In the hypothetical example of DCCA output (figure 6.2.2.1), we can make the following conclusions:

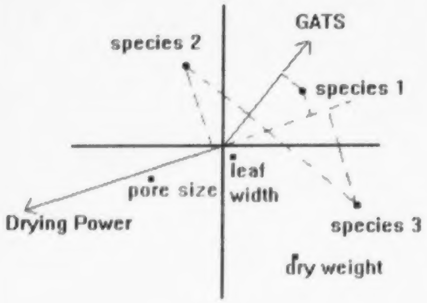


Figure 6.2.2.1: Hypothetical DCCA output.

⇒ More variation between species is accounted for by drying power than GATS.

⇒ *Reason: The eigenvector for drying power is longer than the GATS eigenvector*

⇒ All species have an identical impact.

⇒ *Reason: Impact does not have an eigenvector in this example*

⇒ Species 1 is the best for GATS, and species 2 and 3 score equal for GATS.

⇒ *Reason: A perpendicular line from species 1 crosses the GATS eigenvector farther away from the center in the direction of the vector (a high GATS) than perpendicular lines from species 1 and 2, which cross at the same point on the eigenvector.*

⇒ Species 3 has the best drying power, and species 2 has the poorest drying power.

⇒ *Reason: Because a low value for drying power is superior to a high value, species that have a perpendicular line that crosses farthest away from the center in the opposite direction of the eigenvector, has the best drying power.*

⇒ A large pore size is related to a high (inferior) drying power.

⇒ *Reason: Pore size plots out near the eigenvector for drying power. A perpendicular line drawn to the drying power eigenvector crosses at a high value for drying power.*

⇒ Dry weight is not highly associated with absorbency characteristics.

⇒ *Reason: Dry weight does not plot near an eigenvector.*

⇒ Leaf width is not associated with drying power any more than it is associated with GATS, or there is little interspecific variation for leaf width..

⇒ *Reason: Leaf width plots out in the center of the chart.*

6.3 Results

6.3.1 Statistical Analysis

Figures 6.3.2.1, 6.3.3.1, 6.3.4.1, 6.3.5.1 and 6.3.6.1 are the plotted output of the CANOCO with the morphological features colour coded. The colour-coded groups shown are not statistically based but serve only as visual aids. In some cases, placement of individual characteristics and species is obscured by these visual aids, so unmodified DCCA output is provided in Appendix 2.

Placement of morphological features and species of *Sphagnum* in the CANOCO is related to subgeneric groupings of *Sphagnum* (figures 6.3.2.1 and 6.3.3.1). Morphological features associated with particular sections of *Sphagnum* form groups in the CANOCO. The relationship between placement of the "pseudo-environmental" features (absorbency characteristics) and morphological features is the most important information. This ascertains associations between absorbency characteristics and morphological characteristics. "Association" does not necessarily mean "causation", and possible functional models and reasons for particular associations are dealt with in later chapters.

6.3.2 All Species, All Absorbency Characteristics

Figure 6.3.2.1 (a) includes all species (table 6.2.1.1) and all absorbency tests (table 6.2.1.2). Unconstrained eigenvalues total 0.533, and canonical eigenvalues total 0.259. *Sphagnum magellanicum* is the best species when considering GATS, drying power and retention capacity. Maximum retention capacity and retention capacity, 1200g are responsible for most of the variation between species according to absorbency characteristics. The GATS scores and impact have the least amount of variation among the species.

SUBGENERIC GROUPINGS

Species in Sections *Sphagnum* and *Acutifolia* have a low (superior) drying power compared to species in the *Cuspidata*. The GATS scores and Retention Capacity are not related to subgeneric groupings.

ABSORBENCY FEATURES

Gravimetric Absorbency Testing System Analysis

GATS is least important in explaining the variation among species. A high GATS is related to the board characteristics of dry weight and density, convex pore frequency and convex pore area. A low GATS is related to the same morphological features that are associated with a high retention capacity at 300g.

Drying Power

A low (superior) drying power (30 minutes) is associated with percent pore area on the convex side, and convex pore frequency. A low drying power (120 minutes) is associated with convex basal pore frequency, convex pore diameter and convex tip and centre pore area.

Impact

Impact is associated only with concave basal pore frequency. There is no strong association between low impact and any morphological feature.

Retention Capacity

High retention capacity is most closely associated with concave pore features, especially concave pore area. A low retention capacity is associated with high convex pore frequency.

MORPHOLOGICAL FEATURES

Leaf Size and Curvature

Leaf length is associated with high (inferior) drying power, but also high retention capacity. Leaf width is most closely associated with low impact and high retention capacity. Leaf curvature is most closely associated with low (superior) drying power (120 minutes). Leaf curvature is associated with mediocre GATS and retention capacity.

Hyaline Cell Size

Hyaline cell lengths plot near the centre of the CANOCO, indicating that cell length is not a good indicator for any of the absorbency features. Hyaline cell width is not near any of the absorbency features, but is placed in-between the pore diameter data, and probably has a similar influence as pore diameter. This is because hyaline cell width is directly related to pore diameter, as cell width is the upper limit for pore diameter.

Pores

Concave and convex pore diameters overlap in the CANOCO because they are usually similar. Concave and convex pore characteristics, other than diameter, are positioned on opposite sides of the CANOCO output.

In general, convex pore features are associated with high GATS and low drying power, while concave pore features are associated with low GATS and high drying power, and high scores for retention capacity. The vector for impact is nearly the "mirror image" line for the concave and convex pore features.

Pore diameter is the character least associated with absorbency characteristics compared to other pore features. Convex pore frequency and percent pore area are the features most strongly associated with high GATS and low retention capacity. Percent pore area on convex side and convex pore area are the most important features for a superior drying power. Percent pore area on the concave side is associated with an inferior drying power.

Fibril Frequency

Fibril Frequency is not associated with any absorbency feature.

Part of Leaf

In some morphological characteristics, all parts of the leaf form groups in the CANOCO analyses. In others, characteristics of the tip, base and center of the leaf are associated with different absorbency characteristics. Basal leaf pore characteristics, especially on the concave side, respond differently from the other parts of the leaf. Centre, tip and mean of all parts of the leaf usually respond similarly. For instance, basal concave pore area is positioned opposite to the pore area of other parts of the concave side of the leaf. Basal concave pore frequency and basal percent pore area on the concave side are also distant from other concave pore features. Convex basal pores are less variable than pore patterns on other parts of the leaf, which is why they respond differently. On the convex side of the leaf, basal pore characters are usually not closely grouped with the other parts of the leaf. Pore diameter is the exception on both sides of the leaf, and basal pore diameter responds similar to other parts of the leaf. Fibril frequency in different parts of the leaf have a similar response.

HABITAT

The habitat of *Sphagnum*, with relation to water table, is most closely associated with a high (inferior) drying power (120 minutes). This indicates that *Sphagnum* from wetter environments have higher drying power than those from drier environments.

BOARD CHARACTERISTICS

Percent water content is positioned near the centre of the CANOCO, indicating that there is not much variation between species. This is expected, since during processing, attempts are made to keep the water content of the boards within a restricted range, so absorbency characteristics are more easily comparable. Percent water is most closely related to the absorbency characteristic of high (inferior) drying power (120 minutes). However, since it is near the middle of the ordination this cannot be interpreted as an important morphological feature. Density and dry weight, two related board features, are important for high GATS and low retention capacity.

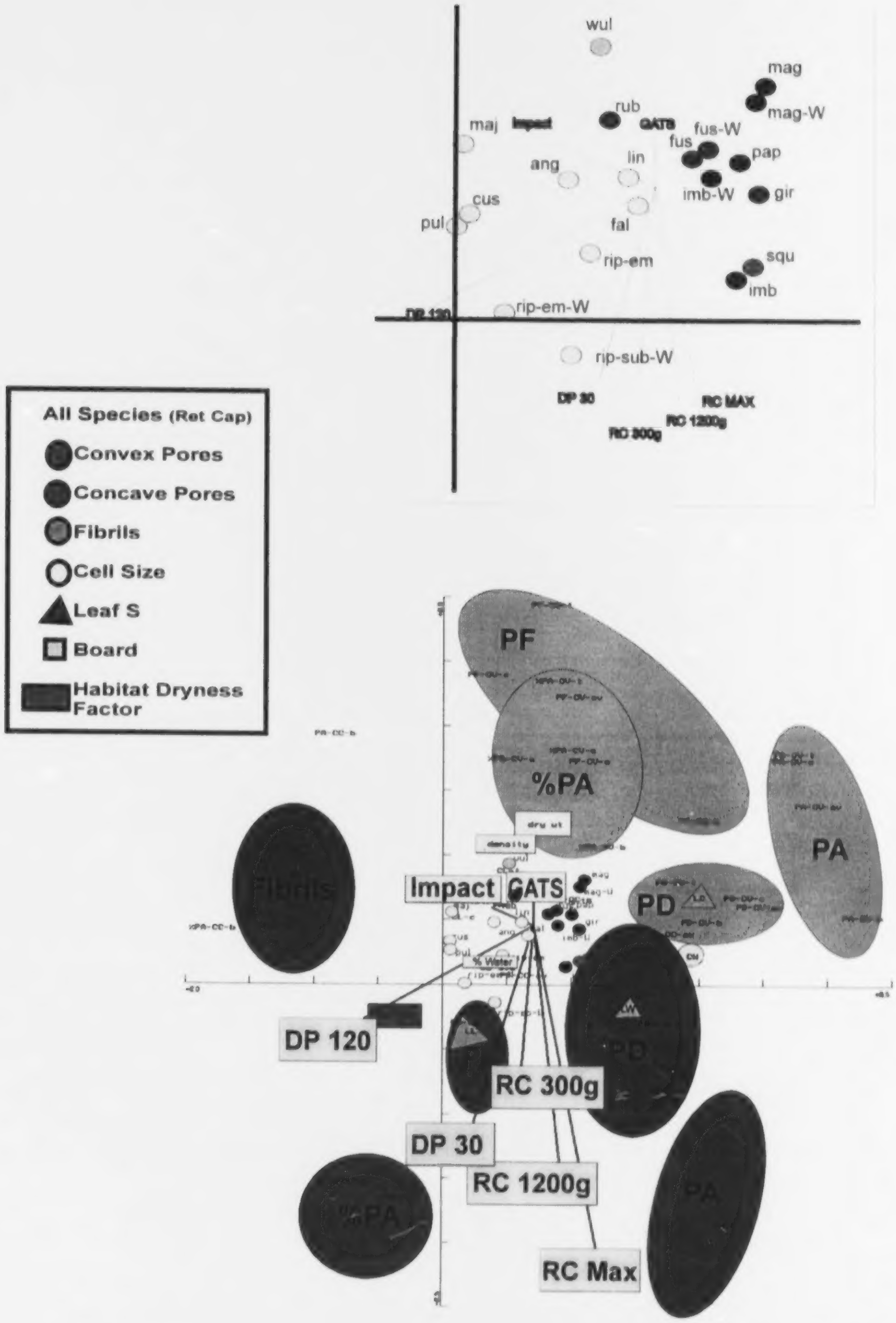


Figure 6.3.2.1: DCCA carried out using all species and treatments (table 6.2.1.1) and all absorbency characteristics (table 6.2.1.3). Unmodified output is in Appendix II. Abbreviations of morphological characters are in table 6.2.1.2. Upper chart contains only the species and absorbency data, lower chart contains morphological, species and absorbency data.

6.3.3 All Species, Retention Capacity Omitted

Retention capacity accounts for most of the variation between the species. In addition, GATS and retention capacity eigenvectors are in opposite directions. Thus morphological characteristics that are important for both may not be so indicated in the CANOCO, as they would be positioned intermediate to both absorbency characters. Retention capacity is a characteristic of the fresh moss, not the finished board, and thus is the least important absorbency characteristic. For these reasons, the CANOCO was also carried out without retention capacity values.

The CANOCO output of figure 6.3.2.1 (retention capacity included) and figure 6.3.3.1 (retention capacity excluded) are similar, but not identical. With retention capacity omitted, drying power (30 minutes) is the most important factor in explaining variation in the data. The sum of all unconstrained eigenvalues is 0.533, and the sum of all canonical eigenvalues is 0.179.

SUBGENERIC GROUPINGS

The groupings of species of *Sphagnum* with retention capacity omitted (figure 6.3.2.1 is similar those with retention capacity included (figure 6.3.3.1). Species in Sections *Acutifolia* and *Sphagnum* outperform those in Section *Cuspidata* and *Squarrosa.*

ABSORBENCY CHARACTERISTICS

GATS

High GATS is most closely associated with convex pore frequency and percent pore area on the convex side. Percent water content and density of the board are also important. A low GATS is most strongly associated with high pore frequency on the concave side.

Drying Power

Low (superior) drying power is associated with convex pore characteristics. Low DP 30 is related to the same characteristics as high GATS (percent pore area on convex side, convex pore frequency, density of board and percent water content of board). Low DP 120 is related to leaf curvature and convex pore area.

Impact

Impact explains the least amount of variation between species. A high value for impact is best explained by a high value for percent water content of the board.

MORPHOLOGICAL FEATURES

Leaf Size and Curvature

Leaf length is most closely related to high (inferior) DP 120, and width to low impact. Leaf curvature is most closely associated with superior drying power (120 minutes)..

Hyaline Cell Size

Degree of association between hyaline cell size and absorbency characteristics varies between the parts of the leaf. Long basal cells are associated with high (inferior) DP 120. Long tip cells are associated with high impact. In the centre of the leaf, long hyaline cells are positioned near the centre of the ordination, and thus are not associated with a particular absorbency feature. Hyaline cell width overlaps with pore diameter features.

Pores

As in the DCCA with retention capacity included (figure 6.3.2.1), the concave and convex pore characteristics in the CANOCO are close to mirror images of one another, however in this case the impact eigenvector is not the mirror image line (figure 6.3.3.1). Convex pore features are associated with high GATS and low (superior) drying power. Concave pore features are associated with low GATS and high drying power. Convex pore area is most closely associated with low DP 120, and concave pore area with very low impact. Pore diameters on concave and convex sides overlap. High convex pore diameter is most closely associated with superior drying power (120 minutes). High concave pore diameter is most closely associated with low impact. Convex pore frequency and percent pore area on the convex side are strongly associated with high GATS values. A high concave pore frequency, conversely, is strongly associated with low GATS values. High values for percent pore area on the concave side are associated with inferior drying power (120 minutes). Basal pore characteristics, (i.e. percent basal pore area, basal pore area and basal pore frequency on the concave side) are not associated with any absorbency feature.

Fibril Frequency

Fibril frequency is not associated with any absorbency feature.

Part of Leaf

Concave basal pore features (except diameter) responds differently than pore features of other parts of the leaf. In the convex side of the leaf, all parts of the leaf are positioned in the same general region of the DCCA output.

HABITAT

Habitat is not closely associated with absorbency.

BOARD CHARACTERISTICS

Dry weight of the board is not important for determining variation between species, and occurs near the centre of the DCCA ordination. Percent water content is associated with impact and density with GATS values.

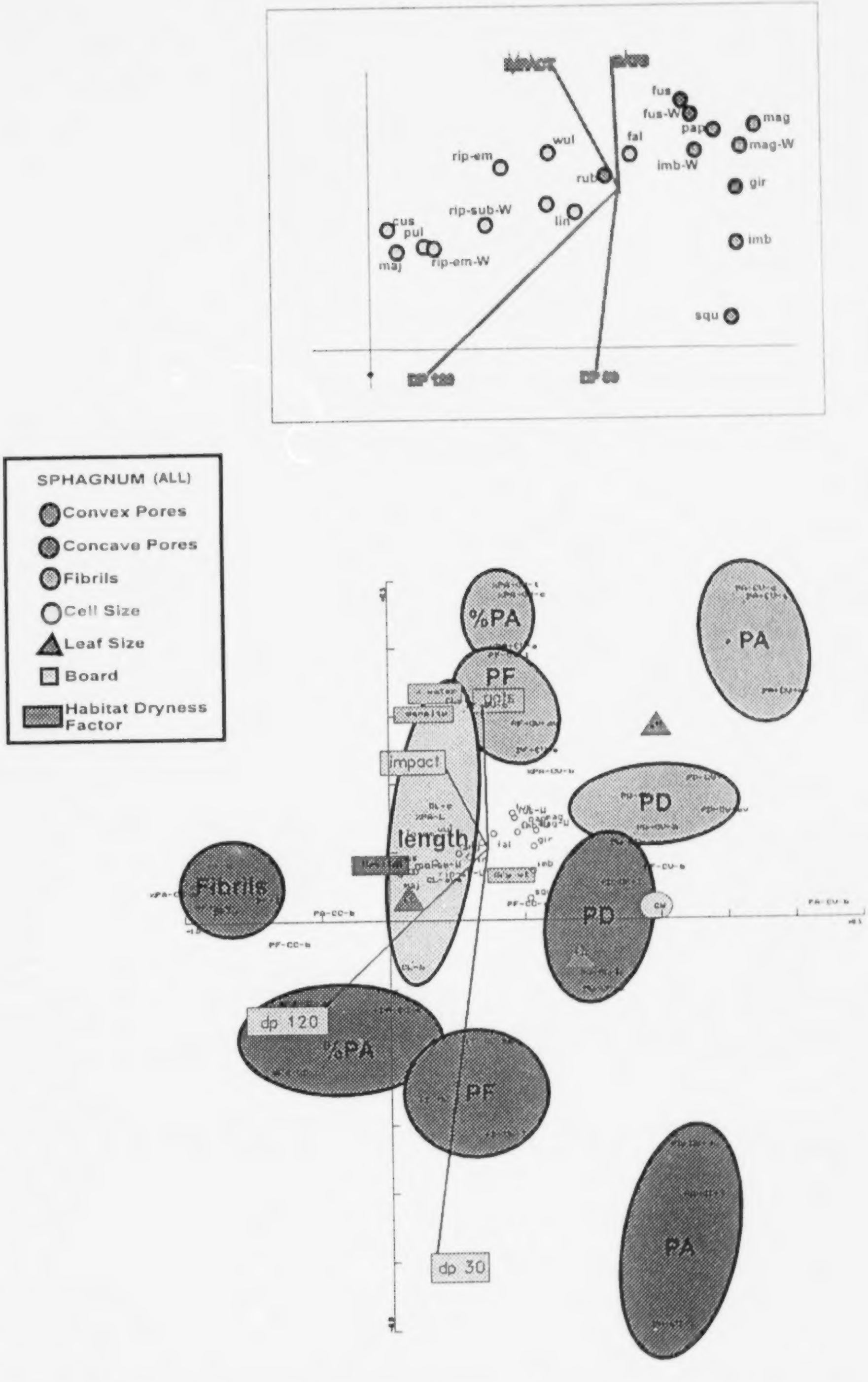


Figure 6.3.3.1: DCCA carried out using all species and treatments (table 6.2.1.1) and GATS, DP 30, DP 120 and Impact (Retention Capacity is omitted) (table 6.2.1.3). Unmodified output is in Appendix II. Abbreviations of morphological characters are in table 6.2.1.2. Upper chart contains only the species and absorbency data, lower chart contains morphological, species and absorbency data.

6.3.4 Section *Sphagnum*

Eigenvalues in DCCA using only species of Section *Sphagnum* (*S. magellanicum, S. imbricatum and S. papillosum*) are the lowest among all of the analyses. Both the sums of the unconstrained and canonical eigenvalues are 0.092, indicating that there is low variation in morphological and absorbency characteristics between species. Therefore, the morphological data do not explain much of the variation in absorbency between species. Other factors which explain the differences must be present.

The eigenvectors are positioned close together (figure 6.3.4.1). Thus, if a morphological characteristic is associated with one absorbency characteristic, it is associated with all absorbency characteristics. Morphological characteristics in the upper portion of the graph are associated with high absorbency, and those in the lower portion are associated with low absorbency. Convex pore characteristics are associated with high absorbency, and concave pore characteristics with low absorbency.

ABSORBENCY

High absorbency is associated with species having low concave pore frequency, low concave pore area and low percent pore area on the concave side. Pore diameter (on concave or convex side) is less important. High dry weight and high percent water content are also important for superior absorbency.

MORPHOLOGICAL FEATURES

Leaf Size and Curvature

Leaf length, leaf width, and leaf curvature are not responsible for much variation between species.

Hyaline Cell Size

Long basal hyaline cells are associated with low absorbency. Other hyaline cell size attributes are not associated with absorbency characteristics.

Pores

High values for convex pore characteristics are associated with superior absorbency, while high values for concave pore characteristics are associated with inferior absorbency. Pore diameter is not as important as pore frequency, pore area and percent pore area on one side of the leaf.

Fibril Frequency

Fibril frequency is not related to any absorbency characteristic.

Part of Leaf

On the concave side of the leaf, pore frequency, area and percent area on the concave side are distinctly arranged in groups according to position on the leaf. These characteristics in the centre part of the leaf correspond with the lowest absorbency, followed by the tip of the leaf, and then the mean pore characteristics correspond to the highest absorbency. There are almost no pores on the basal part of the leaf on the concave side, so basal pores were not included in the analysis.

Habitat

Habitat is not associated with absorbency performance.

Board Characteristics

Dry weight and percent water content of the board are strongly associated with superior absorbency. High board density is also associated with very high absorbency, but is positioned further from the group of vectors than the other board characteristics.

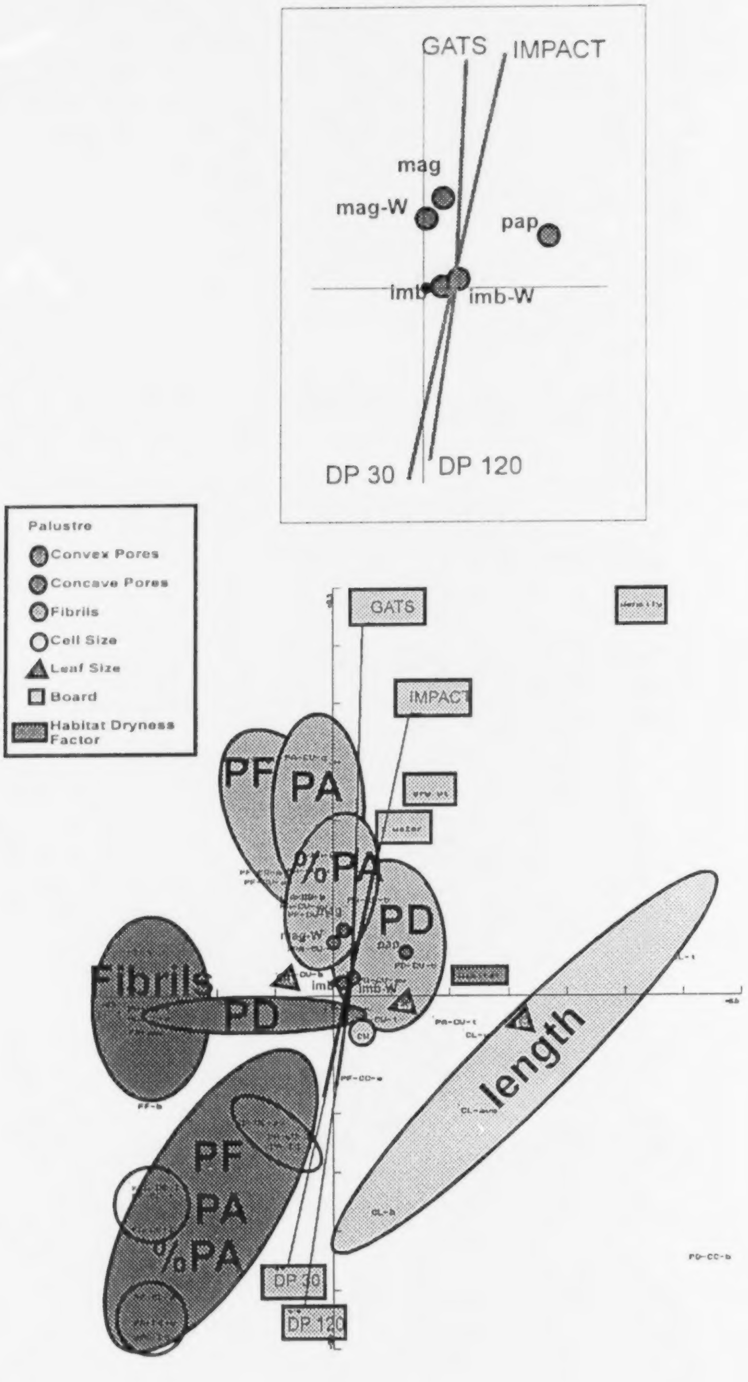


Figure 6.3.4.1: DCCA carried out using species in Section *Sphagnum* (table 6.2.1.1) and GATS, DP 30, DP 120 and Impact (table 6.2.1.3). Unmodified output is in Appendix II. Abbreviations of morphological characters are in table 6.2.1.2. Upper chart contains only the species and absorbency data, lower chart contains morphological, species and absorbency data.

6.3.5 Section *Acutifolia*

Since all boards in Section *Acutifolia* scored 100% for impact, it was not included in the DCCA analysis for this group. The eigenvectors for GATS and drying power are near to one another and in the same direction. Those morphological characteristics associated with high GATS are also associated with high (inferior) drying power.

The sums of all unconstrained and canonical eigenvalues are 0.220 therefore much of the variation between species is not explained by the data.

ABSORBENCY CHARACTERISTICS

GATS

GATS is the least important vector in this ordination, thus GATS explains less of the variation between species than drying power. High GATS is not closely related to any morphological characteristic. It is, however, related to habitat water availability and board dry weight. Low GATS is associated with large pore diameters (on either concave or convex side), and basal hyaline cell lengths. Leaf length is associated with low GATS.

Drying Power

High (inferior) drying power is associated with high leaf curvature, and high pore frequency on the convex side. Low drying power is associated with high pore diameter and large hyaline cell lengths and widths. Pore diameter is positioned near the centre of the ordination, and therefore does not explain a large amount of variation between species.

Impact

Since all the values for impact are similar in the Section *Acutifolia*, it is not possible to determine the morphological features responsible for impact.

MORPHOLOGICAL FEATURES

Leaf Size and Curvature

Leaf curvature is closely associated with high (inferior) DP 30, and a high GATS value.

Hyaline Cell Size

Long hyaline cell lengths are most closely related to low drying power and a low GATS value. Wide hyaline cells are most closely associated with a low GATS value. Cell width is related to pore diameter, since the maximum pore diameter is the width of the cell. Cell width and pore diameter overlap in the ordination.

Pores

Convex pore frequency is associated with low GATS, while concave pore frequency is not associated with any absorbency characteristic. Pore area and percent pore area on one side of the leaf are not strongly associated with any absorbency characteristic. However, those species with larger pore area on the convex side do have a higher GATS than those with larger pore area on the concave side. Pore diameter (on either side of the leaf) is near the centre of the ordination (especially convex pore diameter) and thus not a good explanation of absorbency variation. Large pore diameters are associated with low drying power and low GATS.

Fibril Frequency

Fibril frequency is not associated with any absorbency characteristic.

Part of Leaf

Concave pore area, percent pore area, pore frequency and pore diameter on the basal parts of the leaf form a group not associated with any absorbency characteristic. Concave pore diameter on the centre of the leaf is also removed from other pore diameter values, and is most closely associated with high DP 30. For other characteristics, individual parts of the leaf form groups.

HABITAT

A wetter environment is associated with a higher GATS value.

BOARD CHARACTERISTICS

Density and percent water content are not related to absorbency characteristics. High dry weight is weakly associated with high GATS (it is near the centre of the ordination).

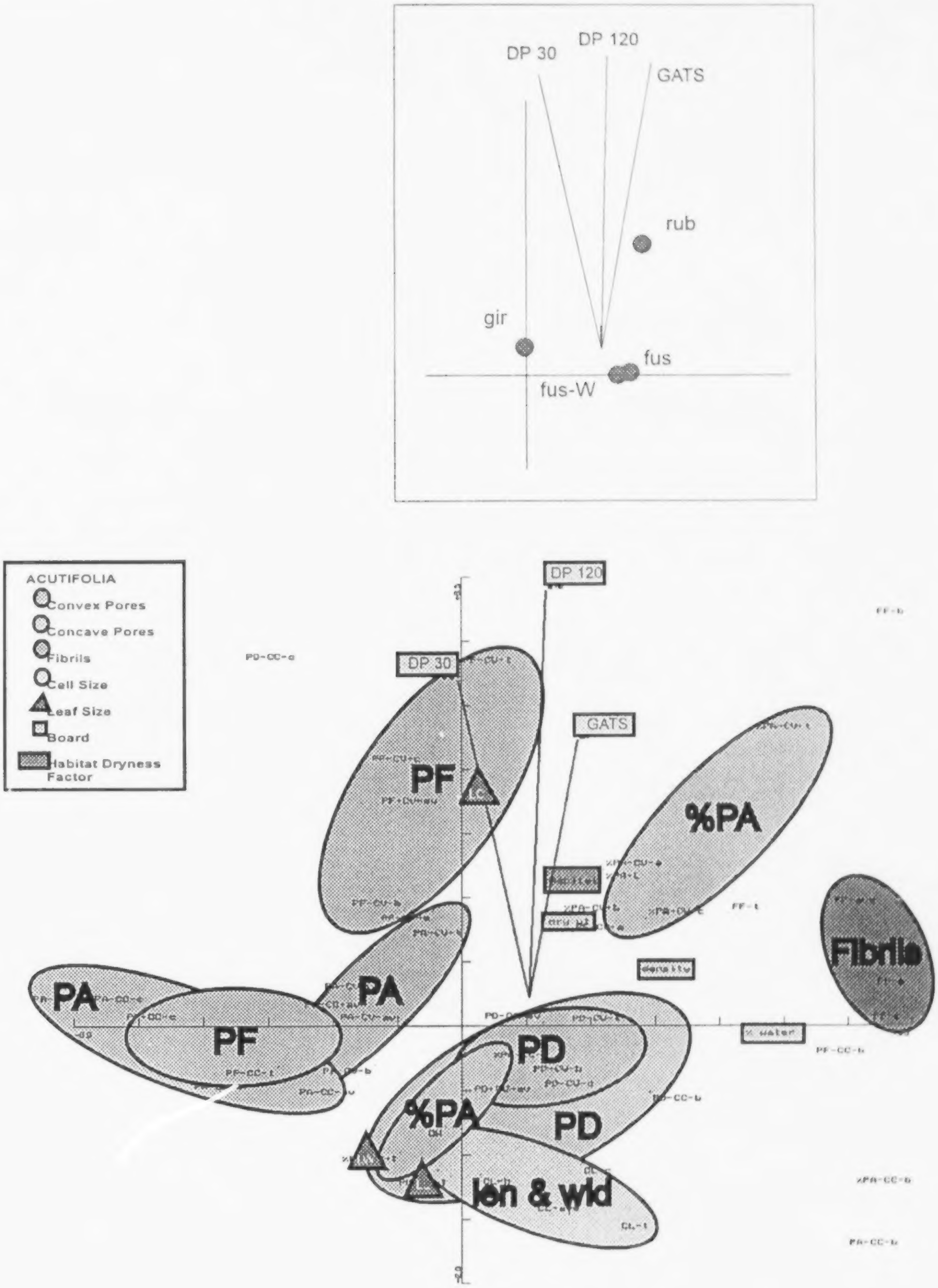


Figure 6.3.5.1: DCCA carried out using species in Section *Acutifolia* (table 6.2.1.1) and GATS, DP 30, DP 120 and Impact (table 6.2.1.3). Unmodified output is in Appendix II. Abbreviations of morphological characters are in table 6.2.1.2. Upper chart contains only the species and absorbency data, lower chart contains morphological, species and absorbency data.

6.3.6 Section *Cuspidata*

The Section *Cuspidata* data (figure 6.3.6.1) explain more of the variation between species than the data of Sections *Sphagnum* or *Acutifolia*. The sum of the unconstrained eigenvalues is 0.463, and the sum of the canonical eigenvalues is 0.277. Morphological features in species of Section *Cuspidata* have more variation than in other sections, and because of this, *Cuspidata* species provide the most information as to the effects of the various morphological features on absorbency.

ABSORBENCY

GATS

High GATS is most closely associated with large convex pore diameters. Low GATS is most closely associated with high board density and high convex pore frequency.

Drying Power

Low (superior) DP 30 is associated with the same characteristics as are superior GATS scores. The same is true with an inferior DP 30 and an inferior GATS score. Low DP 120 is related to large concave pore diameters and mean percent pore area on the concave side. High DP 120 is related to high percent pore area on the tip of the convex side of the leaf, large convex pore area, and hyaline cell size.

IMPACT

High impact is most closely related to high percent water content in the board, and a large leaf curvature. Habitat water availability and cell width are less important. Large convex pore diameter is also associated with high impact, but not as closely as the other features mentioned. Low impact is associated with high board dry weight.

MORPHOLOGICAL FEATURES

Leaf Size and Curvature

Leaf curvature is associated with high impact. Leaf length and width are not associated with any absorbency characteristic.

Hyaline Cell Size

Long hyaline cells are associated with high drying power. Wide hyaline cells are associated with high impact. However, cell width plots out near the centre of the ordination, and thus cell width is relatively unimportant.

Pores

Pore diameters, on either side of the leaf, are associated with high absorbency. Pore area is associated with drying power. Convex pore area is associated with high (inferior) drying power, and concave pore area is associated, though not directly on the vector, with low drying power. Percent pore area is less important for absorbency characteristics. Convex pore frequency is strongly associated with a poor drying power, and a poor GATS score. However, concave pore frequency is not strongly associated with any absorbency characteristic.

Fibril Frequency

Basal fibril frequency is correlated with a poor GATS and a poor Drying Power. Fibril frequencies on other parts of the leaf are not related to any absorbency characteristic.

Part of Leaf

There are no obvious patterns with regards to the part of the leaf.

HABITAT

Wet habitats are weakly associated with high GATS score.

BOARD CHARACTERISTICS

Percent water content of the board is associated with high impact, and high dry weight with low impact. High board density is associated with high drying power (30 minutes).

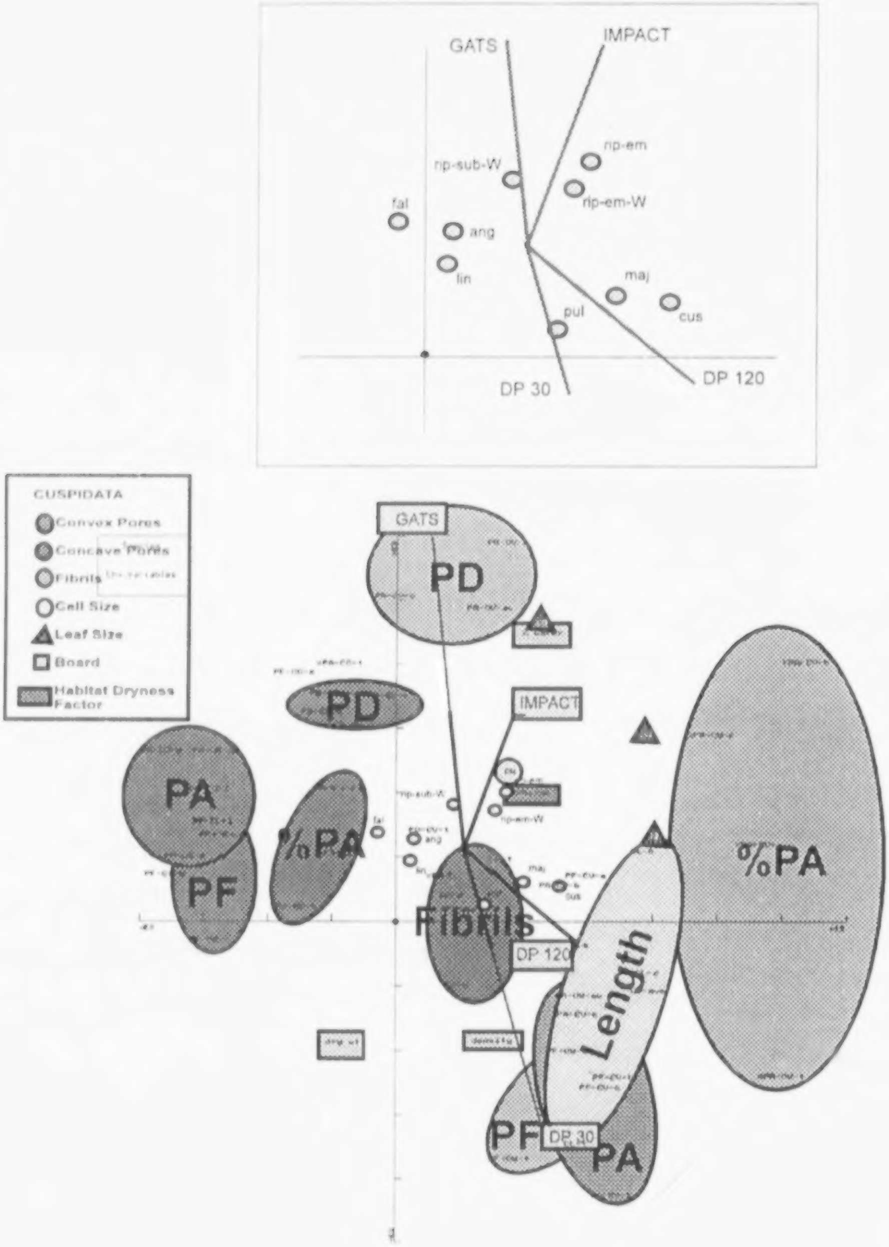


Figure 6.3.6.1: DCCA carried out using species in Section *Cuspidata* (table 6.2.1.1) and GATS, DP 30, DP 120 and Impact (table 6.2.1.3). Unmodified output is in Appendix II. Abbreviations of morphological characters are in table 6.2.1.2. Upper chart contains only the species and absorbency data, lower chart contains morphological, species and absorbency data.

Chapter 7: Discussion

7.1 Introduction

Sphagnum board manufactured with fresh moss from the surface of a peatland has superior absorbency to boards manufactured from mined peat. Drying power is improved up to 500% and GATS scores are increased up to 82%. In most boards made with fresh material, impact is 100%.

Out of the sixteen species tested (*Sphagnum angustifolium, S. cuspidatum, S. fallax, S. fuscum, S. girgensohnii, S. imbricatum, S. jensenii, S. lindbergii, S. magellanicum, S. majus, S. papillosum, S. pulchrum, S. riparium, S. rubellum, S. squarrosum,* and *S. wulfianum*) *S. magellanicum* has the greatest overall absorbency, *Sphagnum fuscum, S. papillosum, S. fallax,* and *S. angustifolium* perform almost as well as *S. magellanicum*. To maximize GATS, the best species are *S. magellanicum* and *S. fallax*. To maximize drying power, the best species are *S. fuscum, S. magellanicum,* and *S. papillosum*. Impact is 100% for all of these species. *Sphagnum wulfianum* has the lowest overall absorbency, but is still superior to commercial board.

7.2 Relationships Between Morphological Characters and Absorbency

Relationships were evident between morphological and absorbency characteristics (table 7.2.1). Leaf curvature is an important morphological characteristic for all absorbency features. The amount of water the board can hold is dependent on how much the board expands. High leaf curvature will maximize expansion. Leaf breakage decreases effective leaf curvature. The probability of leaf breakage during processing increases with leaf size. Leaves with a curvature greater than 300 micrometers were more prone to breakage during precalendering processing than leaves with a smaller curvature. Morphological characteristics that affect breakage will in turn affect absorbency. To maintain leaf integrity, it is optimal for most of the tip, central and basal pores to be on one side of a leaf (concave or convex side), at least on any given portion of the leaf. Edge pores on both sides of the leaf do not affect leaf integrity. For drying power, in addition to leaf curvature, large pore diameter, and pore area are

Table 7.2.1: Associations between absorbency of *Sphagnum* board and morphological features of *Sphagnum*. Italicized features are most closely associated with the respective absorbency characteristic (based on relative distance of placement of morphological feature to absorbency.

High GATS
Percent Pore Area on Convex Side
Convex Pore Frequency
Hyaline Cell Length - Tip
Water Content
Leaf Curvature
Convex Pore Area
Convex Pore Diameter

Low GATS
Concave Pore Frequency
Percent Pore Area on Concave Side
Pore Area Convex Side
Hyaline Cell Length - Base
Leaf Width
Concave Pore Diameter

Low Drying Power
Convex Pore Area
Leaf Curvature
Pore Diameter
Percent Pore Area on Convex Side
Hyaline cell length - tip of leaf
Board Density
Board Water Content

High Drying Power
Percent Pore Area on Concave Side
Concave Pore Frequency
Concave Pore Area
Fibril Frequency
Hyaline Cell length - base of leaf

High Impact
Convex Pore Frequency
Percent Pore Area on Convex Side
Percent Water Content of Board
Density of Board
Hyaline Cell Length - Tip

Low Impact
Concave Pore Area
Concave Pore Frequency
Concave Pore Diameter
Leaf Width
Hyaline Cell Width

High Retention Capacity
Concave Pore Area
Concave Pore Diameter
Percent Pore Area on Concave Side
Concave Pore Frequency
Leaf Length
Leaf Width
Habitat

Low Retention Capacity
Convex Pore Frequency
Percent Pore Area on Convex Side
Convex Pore Area
Concave Pore Area - basal

Table 7.2.1b: Summary of Optimal Characteristics:

Morphological Characteristics
Large leaf curvature (up to 300 μm)
Pores mostly on one side of the leaf (to prevent breakage)
Large pore diameter
Large pore area

Board Characteristics
High density of board
High water content of board

important. A high board density also is associated with a superior drying power. Impact is associated with a high water content and high board density.

Some morphological characteristics were found to be unimportant for absorbency. Hyaline cell size and fibril frequency are examples of this. Fibrils prevent the individual hyaline cells from collapsing and breaking under pressure, and are probably involved in re-assuming the original leaf shape upon rehydration. Since fibrils occur in the hyaline leaf cells of all species, it is not possible to test the effects of the absence of this characteristic has on absorbency. Hyaline cell shape, however, may be involved in the type of leaf breakage that occurs, and thus may be indirectly affecting absorptive properties. Shape, however, was not quantified and could not be examined using the CANOCO program.

Cell width and cell volume are not important for GATS values. Cell width and volume are related to pore size, since the maximum pore size is the width of the cell. To illustrate the fact that cell width is not important, a simple example is used (figure 7.2.1). There is a 0.5% difference in the volume occupied by water in a cross section of leaf with a width of 20 μm versus one with a cell width of 14 μm (figure 7.2.1). These values were chosen for the illustration because *S. fuscum* (20 μm) and *S. rubellum* (14 μm) have similar cell shape, but different widths. The standard deviations for GATS of *S. fuscum* and *S. rubellum* overlap.

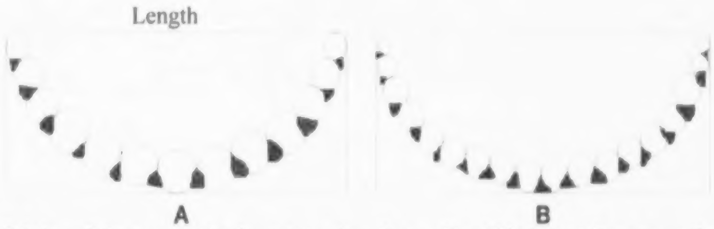


Figure 7.2.1: Diagrammatic demonstration that cell width is not important in determining total GATS value. "A" has a cell width of 20 μm while "B" has a cell width of 20 μm. There is only a 0.5% difference in GATS between "A" and "B", assuming each hyaline cell is perfectly round, and each chlorophyllous cell is a triangle 7X7 μm. (does not account for overlap) where:

GATS of transverse section = Length X Width - Transverse-sectional Leaf Area

For "A", cross-sectional GATS is 18712 μm^2, and 18808 μm^2 in "B".

7.3 Summary of Board Action

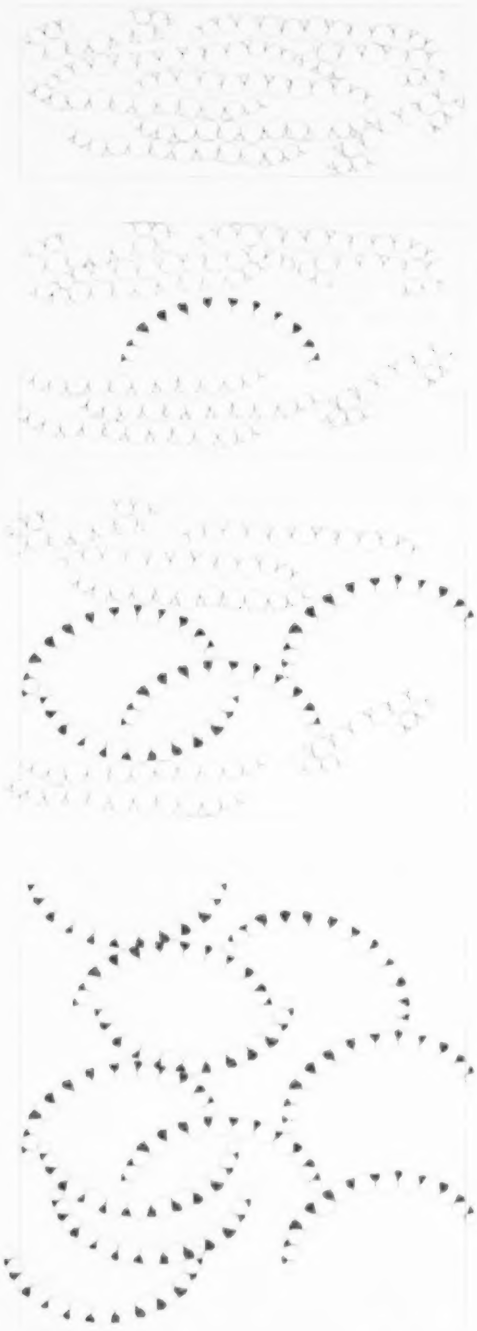
Upon rehydration a calendered leaf or leaf fragment regains the original shape it held in the fresh moss. Unbroken leaves in calendered and uncalendered board are identical in all morphological respects, (including leaf curvature) upon rehydration.

After calendering, the leaves (and other board components) are tightly compressed together in a thin sheet. According to the SEM analysis, hyaline cells are not completely collapsed due to calendering (but may be wrinkled or compressed). The fibrils prevent complete collapse of the hyaline cells, and are probably involved in expansion on rewetting. Water is able to enter each cell and each leaf as it would in a natural situation. Surfactants are added to counteract the hydrophobic nature of dry *Sphagnum* aiding rapid entry of water into the board..

As an individual leaf rehydrates and regains its curvature, the action is similar to that of an eyedropper as the bulb is released (figure 7.3.1). Water is drawn into the board as the leaves expand. The greatest possible water holding capacity of the board is equivalent to the amount of air space present in the board plus the difference in volume between the calendered and expanded board.

For most morphological characteristics, it is difficult to determine the exact role in absorbency. The multivariate analysis CANOCO is used to identify what morphological characteristics are *associated* with superior and inferior absorbency. However, an association does not mean *causation*.

In some cases, a morphological feature is indirectly related to absorbency. The most consequential morphological features affect degree of leaf breakage, which affects the effective degree of leaf curvature, which in turn affects the amount of water the board can hold. For instance, according to the CANOCO, hyaline cell size and shape have little direct influence on absorbency, but they play a role in establishing the type of leaf breakage that occurs.



A. Diagrammatic transverse section of small segment of dry, calendered board.

B. Water is introduced from the side. As leaves expand, they are forced to rearrange. Height of board increases as leaves expand.

C. Water is channeled through board due to capillary action. The ability of the board to wick water away from a source is the drying power.

D. Board is completely expanded. GATS in this section of the board is the total amount of air space in "A" plus the difference in height between "A" and "D" assuming water occupies all free space in the board. Impact is affected by how hydrophilic the board is, and thus how rapidly uptake of water occurs.

Figure 7.2: Diagrammatic summary of board action.

7.3.1 Summary of GATS Analysis

The GATS score is affected more by the gross structure of the leaves of individual species of *Sphagnum* than on ultrastructural cell morphology. A high leaf curvature is important in GATS scores. Effective leaf curvature is affected by leaf breakage. Species whose leaves are more curved and are resistant to breakage will have a higher GATS than those whose leaves are flatter, and/or more easily broken. Pores are important for their role in leaf breakage. Leaves with numerous pores on both sides of the leaf are more prone to breakage than leaves with fewer pores, or pores almost entirely on one side of the leaf. Species where leaves are all of a uniform size to prevent the "stacking stool effect" will have a larger percentage of the leaves involved in board expansion and will thus have a higher GATS score. Board made from fresh moss will have a higher GATS score than board made from peat that has undergone partial decomposition, since the leaves will be less likely to break thus there is a higher percentage of leaves contributing to GATS, and spaces in between leaves will have fewer small leaf fragments displacing water. The effect of the whole plant treatment depends on stem morphology. Species with supple stems will have a lower GATS, as the stems displace water, without adding to water holding capacity. Species with wiry stems that create a more open board structure will have equal or higher GATS in whole plant treatments as compared to leaves only treatments. In species with a well-developed hyalodermis in the stem, consisting of large porose hyaline cells, GATS may not be detrimentally affected by use of whole plants since the stems may hold water, in addition to creating a more open board structure.

7.3.2 Summary of Drying Power Test

As calendered leaves regain their original shape upon rewetting, the board expands and liquid is drawn into the board. Leaf curvature (and thus all morphological characteristics affecting leaf damage) is associated with this. However, drying power is not merely a factor of how much the board expands, as is GATS, but is a factor of how efficiently liquid is drawn away from a source. This efficiency is dependent on the continuity of the water column in the board, and whether or not fluid migration is impeded by particulate matter (Yvon Levesque, pers. com.).

Drying power in monospecific board is superior to that of commercial board. Commercial board contains more fragmented leaves and other small particles than monospecific board because of decomposition. These particles impede lateral fluid migration. The use of fresh, non-decomposed moss would circumvent this problem, and greatly improve drying power in the finished product. Or, a more efficient method of removing particulate matter should be devised. However, this may be counter-productive, as the partially decomposed leaves may be prone to breakage due to processing, and extra screening and processing could result in more breakage. Large, numerous pores on one side of the leaf are important in lateral wicking, an integral part of drying power. Whole plant treatments have an inferior drying power as compared to leaves-only treatments, because the inclusion of stems in whole plant treatments results in a more open board structure, which disrupts the continuity of the water column. Stem morphology affects the degree to which this occurs.

7.3.3 Summary of Impact Test

Impact is a measurement of how hydrophilic the board is. If water immediately enters, then the impact is high. If water runs off, then impact is low. Impact is most affected by the hygroscopic water content and density of the board. A high water content and a high density of the board are related to high impact values. Pore diameter is also associated with impact.. When all species are considered, a large pore diameter has a negative effect on impact, but, when examining individual taxonomic sections, pore diameter has a positive effect on impact. Large pore diameters allow water quick entry into the hyaline cells.

7.3.4 Summary of Retention Capacity Test

Retention capacity is not a feature of the board, but of the moss slurry used to prepare the board. Most of the conclusions with regard to associations between morphology and absorbency are based on CANOCO diagrams that do not include retention capacity. When retention capacity is included, maximum retention capacity is the most important absorbency characteristic for determining the variation between species. The eigenvectors of all RC Max, RC 1200g and RC 300g are in approximately the same direction, so all three are associated with the same morphological features. The vector for GATS is in the opposite direction, indicating that morphological features associated with a high GATS are the same features associated with a low retention capacity. This is contradictory to what is expected, since both are measurements of water holding capacity. It is probably not the morphological features of the individual leaves that account for the different results between GATS and retention capacity, but differences between the board and the slurry. There were numerous variables in this slurry (such as stem to leaf ratio, size of particles, stem morphology) that are not accounted for in the morphological data.

A good retention capacity does not necessarily mean that the rest of the absorbency characteristics will also be good. For instance, *S. squarrosum* and *S. imbricatum* both have inferior absorbency, except for high scores for maximum retention capacity.

The three retention capacity test values have differing amounts of variation between species. RC Max has the highest degree of variation (coefficient of variation), followed by RC 300g and RC 1200g (this is also indicated in the CANOCO diagram by length of vector). Under pressure, all species of *Sphagnum* lose at least half of the maximum amount of water they can hold. Some lose up to three quarters, but the average is about 60%. Most of this water is not from the leaves but from the area surrounding the leaves, because 1200g of pressure will not provide sufficient force to counteract the strong capillary forces holding water inside the hyaline cells. As the *Sphagnum* plug is compressed, water is forced out as volume is reduced.

High maximum retention capacity does not ensure high retention capacity under pressure. For instance, *S. squarrosum* has a high RC MAX, but under pressure loses a greater percentage of water than all other species. In the natural system, *S. squarrosum* occupies a habitat with a varying water table, and therefore requires the ability to store as much water as possible when available. Thus, it has a high water retention capacity. Water retention under pressure would not be important since this does not apply to the natural habitat. The large pores found on both sides of the leaf allow rapid movement of available water into the hyaline cells.

7.4 Commercial Board vs. Handsheets

Absorbency of monospecific handsheets is higher than the absorbency of the commercial product in all respects. There are several possible explanations for the increased absorbency in the monospecific handsheets compared to the commercial product. 1. Decomposition in the commercial moss material produces particulate matter that does not contribute to the water holding power reducing GATS scores, and impedes lateral flow of Pr-SPTF-1 negatively affecting drying power (figure 7.4.1). During commercial *Sphagnum* board production, fine particles are screened out, but cannot be 100% removed. 2. Greater amounts of leaf breakage in the commercial board compared to the monospecific board results in a smaller leaf curvature of the individual pieces, and thus a reduced GATS score. There is more leaf breakage in boards made from mined peat material than in boards made from fresh moss. The amount of decomposition in the mined peat material will depend on the depth of the peat (and therefore the length of time it has been decomposing), and perhaps the species composition of that peat. Szumigalski and Bayley (1996) determined that *S. fuscum* and *S. teres* (Schimp.) Angst. *ex* C. Hartm. showed a similar amount of decomposition after two years in a bog (*S. fuscum*) and a poor fen (S. teres). However, Johnson et al. (1990) found that hollow species undergo more rapid decomposition than hummock species. Decomposition in the commercially harvested material may affect the structure of the walls making the leaves less resilient and more prone to breakage during processing. 3. There is a potential for more non-*Sphagnum* debris, such as small pieces of *Carex* leaf blades, present in commercial field material than in hand picked fresh material. The fibres (kraft and polyester) present in the handsheets and commercial material reduce GATS scores (Appendix 3, results of a previous study by Johnson and Johnson where boards were prepared without these fibres), but are necessary to prevent breakage of the board under handling.

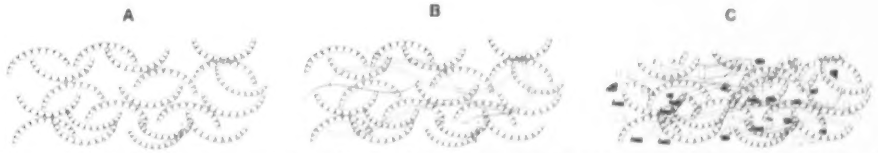


Figure 7.4.1. Comparison between a board containing leaves only (A), leaves plus fibres (B) and leaves plus particulate debris (C). GATS is represented by the amount of space between the leaves, fibres and particulate matter, and within the hyaline cells. Diagrammatic; not intended to represent actual ratios present.

7.5 Effects of Treatments and Board Characteristics on Absorbency

7.5.1 Habitat

Samples of *S. riparium* from different habitats (growing submerged in a pool and growing emergent at the edge of a pool) have similar absorbencies. Multivariate analyses show that habitat is not strongly associated with high or low absorbency. Only retention capacity is associated with habitat. A wetter habitat is associated with a high retention capacity.

7.5.2 Whole Plant Treatment

The use of whole plants in *Sphagnum* board tends to reduce absorbency. However, in some species the adverse effects are less pronounced, depending on stem morphology which was not analyzed in this study. Even when whole plants are used, absorbency is still greater than commercial results for GATS and drying power, but impact is greatly reduced in *S. imbricatum*. Whole plant treatments do not affect GATS in *S. magellanicum*, increase GATS in *S. riparium*, and decrease GATS in *S. fuscum* and *S. imbricatum*. Whole plant treatments do not affect drying power in *S. fuscum*, decrease effectiveness of drying power in *S. magellanicum* and *S. riparium*, and increase the effectiveness of drying power in *S. imbricatum*.

Whole plant treatments and their affect on GATS seem to be related to density, except in the case of Section *Sphagnum*. In Section *Sphagnum*, the CANOCO output indicates that high density and high GATS are related, but not closely since density is removed from the GATS eigenvector. In *S. magellanicum,* lower density has no effect on GATS performance, while with *S. imbricatum*, the whole plant treatment had both lower density and a lower GATS score. The difference could be related to stem and branch morphology, which were not analyzed in the study. According to Crum (1984), the stem and branch hyalodermis of both species differ. In *S. magellanicum*, the stem hyalodermis consists of four cell layers. The outer layer has one pore per cell, and is also fibrillose. The branch hyalodermis consists of one layer of large hyaline cells that also have a single pore and are fibrillose. In *S. imbricatum*, branch morphology is similar except that the hyaline cells are slightly smaller. The stem hyalodermis also has four layers, but the outer layer has numerous small pores per cell, rather than one large one. It may be that the hyalodermis of the stem of *S. magellanicum* has a better water holding capacity than that of *S. imbricatum*, given the difference in the GATS results for the comparison between whole plants and leaves only treatments.

Board density of the whole plant and leaves-only replicates of *S. riparium* were similar. As well, the GATS scores were approximately the same, and both had high scores. In this group, enlarged porose/fibrillose hyalodermis cells are not present, so the stem displaces water rather than absorb it in the GATS test. The large particles of stems and branches disrupt the layering of the leaves, producing a more open structure, having a positive effect on GATS scores (this same feature has a detrimental effect on drying power).

In the whole plant board, since screening of leaves does not take place, more of the leaves are left in place on their respective branches. When these larger intact pieces expand, the total expansion in all directions results in more empty spaces than in boards made with leaves only. To have an equivalent GATS score in both treatments, sufficient pore spaces must be opened up to make up for water displaced by stem volume. The presence of branches and stems in the board, and the resulting open structure, may also explain why *S. jensenii*, made with whole plants (and the least dense treatment of all), outperformed *S. lindbergii and S. cuspidatum*, two other species in Section *Cuspidata* made with leaves only. This result may also be related to leaf curvature.

With *S.* fuscum, inclusion of branches and stems results in a decrease in GATS scores. In *S. fuscum*, the branch hyalodermis is one layer of retort cells (large siphon-shaped hyaline cells). The stem hyalodermis is three layers of non-porose cells. The stems are thinner and less wiry than in *S. riparium,* where the hyalodermis is poorly developed. Perhaps, because of the suppleness, and small size of the stems in *S. fuscum* as compared to *S. riparium*, the stems conform to the particles around them, rather than providing obstructions around which the other particles must conform. The presence of stems in *S. fuscum* board does not result in a more open board structure, thus total volume is not increased. Water displaced by the stems results in a decrease in GATS scores. In the natural situation, wiry stems are not necessary in *S. fuscum*, since stems are supported by surrounding plants in a compact hummock. In *S. riparium*, wiry stems are important in keeping the capitulum upright, as this species has a looser growth habit.

Most of the samples have an impact of 100%. Addition of stems to the board is not beneficial for impact. In the case of *S. imbricatum*, the whole plant treatment had less than half the impact of the leaves only treatment. *Sphagnum jensenii* was the only species in Section *Cuspidata* made with whole plants for which impact was measured, and has the lowest impact out of species in this section.

Stems in the material probably also affect retention capacity results, although stem morphology was not analyzed. For instance, *S. riparium* appeared to have a higher stem to branch ratio than the other species, especially in the submerged sample (this was not measured). *Sphagnum riparium* has the largest RC Max out of all the species. The stems in the slurry result in a more open structure in the *Sphagnum* plug thus increasing water holding capacity. Since most of this water held between the branches and stems, this species loses a greater percentage of water under pressure than any of the other species in Section *Cuspidata*. This is not due to the morphological structures of the leaves, but to the stem-to-branch ratio.

7.5.3 Effects of Board Characteristics

In boards that are made of leaves only, a high density means that there is a larger amount of solid material, mostly leaves, in a given amount of board compared to a board with a lower density. Since GATS is corrected for weight of the board rather than volume, density is not important for the leaves-only board. When stems are added, density may be affected depending on stem morphology. The GATS scores, in whole plant board, are affected by density.

When all species are included, density is associated with a high GATS score. In the CANOCO for species of Section *Cuspidata*, high density is related to a low GATS score Lowest density boards are those made with whole plants. Boards made with whole plants have a higher GATS than those made with leaves only (in Section *Cuspidata*). In species of Section *Acutifolia*, density has no effect on GATS, and in species of Section *Sphagnum*, density is associated with a high GATS score. These results are also related to whole plant treatments.

In all CANOCO analyses, except for Section *Acutifolia*, water content of the board is associated with a high GATS score. When all species are included, water content is highly associated with a high GATS score. One possible explanation is that boards with a high water content are simply those boards that lose water least rapidly during their preparation. When handsheets are produced, the *Sphagnum* slurry is placed on a small forming table composed of a frame and a screen. Suction is applied from below the forming table. Some species become dry enough to remove from the table quickly (Section *Cuspidata*) while others (*Section Acutifolia*) take longer. Boards with the highest GATS would naturally retain the most water during handsheet formation, and it would take longer for such a board to dry down to the appropriate water content for absorptive tests. In this case, it would not be the water content that is affecting the high GATS of the board, but rather the high GATS capacity of the board that is affecting the high water content of the sample. In order to determine which scenario is true, boards made from the same material and prepared in identical ways, except dried to different water contents, need to be prepared. Then, a correspondence analysis should be done to determine if GATS is affected by water content of the board.

Another possible explanation is that leaves that are dried to a higher degree may be more prone to breakage upon board expansion. Leaves with a higher moisture content may remain more supple, and are more resistant to breakage while in storage before absorbency tests. In Section *Cuspidata*, this may be the case, since the three species with the highest water contents had the least amount of breakage. A similar correlation was not found in the other groups. This may be related to the presence of pores on both sides of the leaf decreasing leaf integrity in some species of Section *Cuspidata* compared to species of Section *Acutifolia*.

A high board density and a high percent water content are associated with superior drying power. A high board density may increase the capillarity of the board. A high percent water content may affect how hydrophilic the board is, which would also affect capillary water movement.

Percent water content is strongly associated with high impact in all sections. Percent water content is the most important factor in determining impact. In species of Section *Cuspidata*, dry weight and density of the board negatively affect impact. The opposite result is seen when all species are considered and in species of *Section Sphagnum*. In Section *Acutifolia*, all species had an equivalent impact, so differentiation based on morphology is not possible.

In species of Section *Sphagnum*, density is associated with a high impact. In this section, only *S. imbricatum* has an impact below 100%. The whole plant treatment of *S. imbricatum* has low absorbency.

It may be board density that is affecting this result. In species of Section *Cuspidata*, density is associated with a poor impact. This may be a related to leaf curvature, which is strongly associated with a high impact. Those species with flat leaves may have a higher density than those with strongly curved leaves. It may be the whole plant treatment that is affecting this result. *Sphagnum jensenii* made with whole plants has a very low density, and it is also the only species of Section *Cuspidata* with a low impact. Dry weight and density are related measurements and have similar associations with absorbency.

7.6 Relationships of Taxonomic Groups to Absorbency

Section *Sphagnum* (*S. papillosum, S. imbricatum* and *S. magellanicum*)

Species of Section *Sphagnum* have most of their pores on the convex side of the leaf. Concave pores are mostly found on the edge of the leaf, where they have little effect on leaf integrity and breakage. Pores are large, and approximately 15 μm in diameter. Since pore diameter is similar between the species it is not possible to determine the effects of pore size on absorbency in this group. However, when all groups are considered together, pore diameter is related to a superior drying power. The principal difference between species is pore frequency (and thus pore area). All three species have approximately the same average pore area on the convex side, and all three have pores on the edge of the leaf on the concave side, but *S. imbricatum* has substantially more pores elsewhere on the concave side than *S. papillosum* and *S. magellanicum*.

Species have a large leaf curvature in comparison to other groups. The leaves are blunt, and have a high leaf curvature along the length of the leaf, rather than just at the base. The leaf tip forms a "hood". The inrolling at the tip, especially the hood, prevent the leaves from being positioned flat on top of one another in the expanded board. *Sphagnum magellanicum* and *S. papillosum* have high absorbency for all characteristics, while *S. imbricatum* has lower than expected absorbency scores. This outcome is probably due to leaf breakage resulting from a combination of two factors. The first, is *S. imbricatum* has more pores on the centre of the concave side of the leaf, and thus has a higher degree of breakage because of lowered structural integrity. Secondly, there is the question of ornamentation on the cell walls, which was not analyzed. *Sphagnum magellanicum* has no ornamentations, *Sphagnum papillosum* has papillae, and *S.*

imbricatum has comb fibrils. These ornamentations may be providing a more rigid structure in the latter two species, which is less resistant to breakage during processing and calendering. For instance, leaves of *S. magellanicum* are not damaged by calendering, while there is a significant difference in the amount of damage between calendered and uncalendered boards of *S. papillosum*. It is unknown whether this is a result of the large leaf curvature or the ornamentations in *S. papillosum*.

Leaves with a curvature of greater than 300 micrometers were more likely to be broken during pre-calendering processing than smaller leaves. The smaller leaves of *S. magellanicum* (with a curvature of about 300 micrometers) is one reason why *S. magellanicum* performed better than *S. papillosum*. If changes in processing procedures were made to reduce the amount of damage to leaves with large curvatures, GATS may be substantially improved when using *S. papillosum*.

The species in Section *Sphagnum* had a higher degree of leaf breakage than other taxonomic sections. Most of the leaf breakage observed in this group was fragmentation. Fragmentation rarely occurs in other sections. One reason for this may be pore patterns. In Section *Sphagnum*, pores often form groups of threes in adjacent cells (figure 7.6.1). This may be a factor in reducing overall leaf strength, especially at junctions between cells, resulting in fragmentation of the leaf during processing.

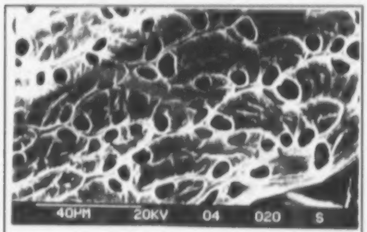


Figure 7.6.1. Pore patterns in *S. magellanicum*.

Fragmentation is the type of leaf breakage that is most detrimental to GATS scores. Most fragments were about one-third the size of an undamaged leaf. In some board samples, there were few leaves that were not broken. However, an individual fragment will still retain its curvature, and can still contribute to water holding capacity. Fragmentation also does not affect pores in most of the leaf cells, and thus drying power is still relatively good.

In the CANOCO analysis, pore characteristics (percentage pore area on concave side, pore frequency and pore area) of the concave side of the leaf form groups according to position on the leaf. Central pores are most important for low GATS, followed by tip pores and average concave pore characteristics are least important. Concave edge pores are not associated with low GATS scores. None of the three species has basal concave pores. Central concave pores would contribute to a low GATS, since a break in the centre of the leaf would have a greater affect on GATS than a break at the tip of the leaf. The degree and type of breakage determine the extent to which GATS is affected.

Section *Acutifolia* (*Sphagnum fuscum*, *Sphagnum girgensohnii* and *Sphagnum rubellum*)

Species in Section *Acutifolia* have small boat-shaped leaves and large pores found mostly on the convex side of the leaf. Curvature is high (for the relative small size of the leaf) along the length of the leaf. In species within *Section Acutifolia*, there is little variation in leaf curvatures between the species. Even with this small amount of variation, a high leaf curvature is still of importance for a high GATS score.

Sphagnum fuscum has a superior drying power. This is an expected result, since wicking power is an important feature in this hummock-forming species. Species in this taxonomic section have a lower amount of breakage than other sections, probably due to the small size of the leaves. When breakage does occur, it is usually across the width of the leaf, near the tip where cells are shorter than in other parts of the leaf. This type of breakage has the least effect on absorbency, since the curvature of an individual fragment is unchanged. Splitting at the base of the leaf was also found, but was not as common as in species of Section *Cuspidata*.

In species of Section *Acutifolia*, convex pore frequency and percentage pore area on the convex side are associated with a high GATS score. Total pore area has an inverse relationship to GATS scores. *Sphagnum rubellum* has the fewest pores and the highest GATS, *S. girgensohnii* has the most pores and the lowest GATS, and *S. fuscum* is intermediate for both. *Sphagnum rubellum* also has substantially smaller pores (and smaller leaves and hyaline cells) than *S. fuscum* and *S. girgensohnii*. The combination of smaller pores, and fewer pores in *S. rubellum* may impart greater ieaf strength. Thus, *S. rubellum* has a higher GATS score. Edge pores do not affect leaf integrity.

Section *Cuspidata* (*Sphagnum angustifolium*, *S. cuspidatum*, *S. fallax*, *S. jensenii*, *S. lindbergii*, *S. majus*, *S. pulchrum*, and *S. riparium*)

Within Section *Cuspidata*, there was more variation in morphological characteristics between species than in the other taxonomic groups. Except for *S. majus*, species in Section *Cuspidata* have most of their pores on the concave side of the leaf, which is opposite to Sections *Sphagnum* and *Acutifolia*. Leaves are acute, with higher curvature in the basal portion of the leaf than the tip of the leaf. therefore, it is mainly the base of the leaf that is contributing to absorbency. Leaf curvature is variable, with some species such as *S. cuspidatum* having nearly flat leaves, and *S. riparium* with some individuals having a curvature of nearly 300 micrometers (the optimal curvature for absorbency).

The most common type of leaf breakage in this group is basal splitting, and splitting along the length of the leaf. The split rarely broke the leaf in two separate pieces, but this type of damage still affects the effective leaf curvature (figure 7.6.2). When a leaf breaks from base to tip, each piece has a smaller curvature than the entire leaf. A corresponding decrease in absorbency is the result. Damage in individual cells, without actual breakage of the leaf causes a "crease", or a basal split in the leaf preventing it from regaining its original curvature (figure 7.6.2c). The effect on total curvature, and thus volume of liquid the leaf can hold, depends on the length of the split. This type of damage frequently occurs in members of Section *Cuspidata* in both the commercial board and the monospecific board. In many cases, the split occurs in the centre of the leaf, where it has the greatest detrimental affect on absorbency. In other cases, the split is about one third (or less) from the edge of the leaf, and is likely the position where the leaf was folded during calendering. A split in this position has less of an effect on water holding capacity.

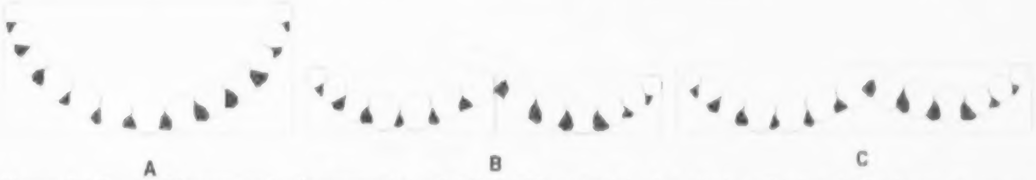


Figure 7.6.2. A. Diagrammatic demonstration of full GATS potential of a single unbroken leaf (shown in cross-section). B. GATS potential of broken leaf, less than half that of unbroken leaf. C. Similar reduction in GATS for creased (or split) leaf. Crease may not extend along entire length of leaf. Total effect on GATS would depend on the position of the crease or split, and how extensive it is. (GATS potential is difference between the area of the rectangle and area of leaf, except for area inside the hyaline cells.)

Breakage across the width does occur in *S. cuspidatum*, especially in species with very long leaves (e.g., *S. cuspidatum*). The type of breakage that occurs is likely related to cell shape. The long, thin cells of species in Section *Cuspidata* likely help reduce breakage across the width of the leaf.

Overall, pores of species in Section *Cuspidata* are about 50% smaller than species in Sections *Acutifolia* and *Sphagnum*, and total pore area is less than half that of species in Sections *Sphagnum* and *Acutifolia* (except *S. rubellum*). Concave pore area is greater in species of Section *Cuspidata* (except for *S. majus*) than in species of Sections *Sphagnum* and *Acutifolia* (except for *S. girgensohnii*).

In species of Section *Cuspidata*, large pore diameter (both sides of the leaf) is the feature most associated with a high GATS score. High pore frequency and large pore area on the convex side are associated with a low GATS score. The effect of percent pore area (%PA) on GATS is dependent on the part of the leaf. High %PA on the basal part of the convex side is associated with high GATS, while on the tip of the leaf high %PA is associated with a low GATS score. Concave pore characteristics, except diameter, are not associated with GATS scores.

The inferior drying power of Section *Cuspidata* as compared to other sections may be due to two factors: (a) fewer, smaller pores (b) low board density. Species with a low pore area may not be as efficient at rewetting of the leaf as species which can uptake fluid quickly. Perhaps adjustment of calendering pressure would improve drying power by increasing board density. However, the drying power in the Section *Cuspidata*, even with species with very few small pores (e.g.: *S. cuspidatum*) is still almost three-fold that of the commercial product.

The low density of Section *Cuspidata* boards also results in a lowered impact. This effect is most pronounced in boards made with whole plants (*S. jensenii*) rather than leaves only. Impact is most associated with convex pore diameter, and weakly associated with concave pore diameter, percent pore area on the convex side (on the base and centre of the leaf) and percent pore area on the concave side (on the tip of the leaf) and concave pore frequency (on the edge of the leaf). Cell width, which is related to pore diameter, is also associated with a high impact. Large pore diameters enable rapid capture of liquid, by allowing quick entry of liquid into the hyaline cells, thus leaves regain their original shape rapidly.

Section *Polyclada*

In the Section *Polyclada*, the spreading and hanging branch leaves are dimorphic. The spreading branch leaves have wide cells, and are most similar to *Acutifolia* leaves. The hanging branch leaves have cell structure that is more similar to the *Cuspidata*. *Sphagnum wulfianum* (*Section Polyclada*) is a forest species. It has a unique structure and is the only species in Section *Polyclada*. No other *Sphagnum* species has more than five branches per fascicle. It has a relatively small pore area, small oval shaped, and strongly ringed pores in the spreading branch leaves, while the hanging branch leaves have pores that are more than three times the diameter of the spreading branch leaf pores. Perhaps the specialized spreading branch pore type in *S. wulfianum* is a water preservation measure. Even with this dimorphic morphology, the spreading and hanging branch leaves have a similar degree of breakage. However, the type of breakage is not necessarily the same (spreading branch leaves have a higher percentage of basal splitting than hanging branch leaves).

Section *Squarrosa*

Board made with leaves of *S. squarrosum* have the second lowest absorbency. Size and distribution of pores are similar to that of *S. girgensohnii*. Since the GATS of *S. girgensohnii* is greater than that of *S. squarrosum*, this difference must be due to factors other than pore characteristics. Since neither of these species are high performers for GATS, the type of pore distribution present in these two species (many pores on both sides) is not conducive to a high GATS, as it probably reduces leaf strength. Unfortunately, there was no *S. squarrosum* board sample to analyze for breakage, since all of the board was used for absorbency tests.

The pore pattern of *S. squarrosum* probably has significance in natural water uptake. When dry, leaves of *S. squarrosum*, are squarrose and it is the concave side of the leaf that is most exposed to the environment. To maximize water capture, it would be advantageous for this species to have a large amount of pores on the concave side of the leaf near the tip, and few on the tip of the convex side. In some species, such as those in Section *Sphagnum*, the leaves within a branch are more or less compressed together when dry. On the blunt tip of a leaf of a species in Section *Sphagnum*, it is the convex side that is more exposed to the environment, which is where the majority of the pores occur.

Figure 7.6.2: The "Stacking Stool Effect" in boards with leaves of dimorphic sizes. Small narrow leaves (usually hanging branch leaves) may settle within larger leaves, and are thus not contributing to the GATS value.

Sphagnum wulfianum and *S. squarrosum* have the lowest GATS in the leaves-only board. A possible explanation for the poor GATS in these species is dimorphic spreading and hanging branch leaves. The hanging branch leaves are half as wide and two-thirds as long as the spreading branch leaves. The smaller hanging branch leaves may settle inside the larger spreading branch leaves, reducing the potential GATS score (figure 7.6.2). This would explain why the GATS scores of these two species are so low, even though leaf curvature is higher than some species, such as *S. fuscum*, that have a much higher GATS but also leaves of similar width on the hanging and spreading branches. Species with a large variation in leaf size may also experience the "stacking stool effect".

7.7 Roles of Absorbency Characteristics in Commercial Applications

Each standardized test absorbency of *Sphagnum* board determines a different aspect of absorbency. Various applications of *Sphagnum* board have different absorbency requirements. Those applications requiring the absorption of a high volume of liquid require a high GATS value. Drying power is important in most applications, but is especially so in hygiene products, since a dry surface ultimately means a greater comfort level. A high GATS would also be beneficial in hygiene products, since a high GATS would mean less absorbent material is needed. Minimizing thickness maximizes comfort level.

The best species for absorbent board, *Sphagnum magellanicum*, performed well in all absorbency characteristics. *Sphagnum* board manufactured from *S. magellanicum* would serve well in any absorbency application for which *Sphagnum* board is used. *Sphagnum fuscum* and *Sphagnum papillosum* absorbed almost as well as *S. magellanicum*. All boards made from fresh moss performed better than commercial board for all absorbency characteristics (GATS, drying power and impact).

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Appendix 1: GATS Analysis Technique

EQUIPMENT

A Gravimetric Absorbency Testing System (GATS) (M/K Systems Inc., Danvers, MA 01923) shown in Figure 2 is used for this test method.

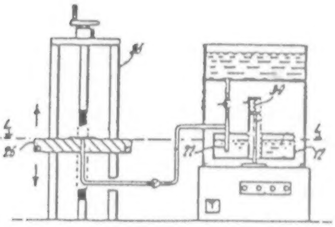

Fig. 2: Gravimetric Absorbency Testing System (GATS).

The major features of this instrument are the fluid reservoir, 12, suspended on an electronic balance by means of a spring, 39, which maintains the fluid level exactly constant whenever fluid moves either into or out of the reservoir by means of the dip tube, 22. Adjustment of sample level in relation to the fluid reservoir level is made by turning the hand wheel on the elevator screw assembly, 36, on which the sample holder plate, 26, is mounted. The electronic balance provides fluid to about ±0.04 gm and the elevator has divisions of 1 mm. The apparatus is described in a U.S. Patent (4) and provides all of the functions required in Swedish Standard SIS 25 12 28 (5). Its use to measure absorbent properties of pulp fluff and rayon webs has been described earlier (6).

To simulate possible changes in loading on the product during use, it is generally recommended that data be collected under different loads. The equipment described herein allows sequential loading. One arrangement for doing this is shown in Figure 3.

a = Loading Weight

b = Acrylic Disk Weight

c = Sample

d = GF/A Disk

e = Fritted Glass Disk

f = Porous Plate

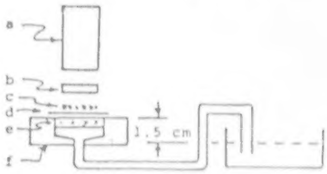

Fig. 3: Apparatus for load cycle testing.

The load cycle is provided by the two weights. The diameter of each is 5.08 cm (2 inches). The larger weight is 684 gm. The smaller weight (acrylic disk) weighs 30 gm. The two weights together produce a load of 3.45 kPa (0.5 psi) and the small acrylic disk alone results in 0.14 kPa (0.02 psi).

The surface of the porous plate is adjusted to a level that is 1.5 cm higher than the surface of the fluid in the reservoir in order to obviate any possibility of siphoning. Fluid is maintained on the surface of the porous plate by means of the fritted glass disk (Class C, Ace Glass, 30-50 micron pore size) which is recessed flush into a well in the acrylic plate.

The powder particles are tested in the form of a thin, uniform layer deposited on a disk of glass microfiber paper (Whatman GF/A). The diameter of the layer of particles is 4.88 cm, which is slightly less than the diameter of the acrylic disk to allow for swelling of the particles. The diameter of the GF/A disk is 6.0 cm.

The particles are deposited uniformly on the GF/A by use of the Powder Deposition Device shown in Figure 4. The stainless steel inverted cone has a 17° expanding angle which permits the uniform spread of powder poured into the top opening.

Appendix 2: Canoco Input and Output

Canoco Input Table 1: Morphological data of board and leaves. Left hand column is species number (which are found in numerical order at the end of the table). Other columns, in sets of two, are scores given for morphological features. The first column is the number of the morphological feature (in sequential order at the end of the table; abbreviations are found in Chapter 6), the second number is the score for that feature scaled from 0 to 100.

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(i2,5(i5,f11.1))
   5
01   01      027.8   02      009.2   03      010.2   04      037.9   05      049.3
01   06      017.8   07      030.6   08      029.7   09      054.1   10      070.6
01   11      012.0   12      046.9   13      024.1   14      032.0   15      027.1
01   16      033.3   17      100.0   18      100.0   19      082.9   20      097.4
01   21      022.9   22      009.3   23      020.7   24      020.6   25      021.4
01   26      083.0   27      043.2   28      100.0   29      022.6   30      046.2
01   31      007.0   32      002.1   33      009.0   34      005.2   35      081.4
01   36      088.7   37      071.9   38      084.6   39      018.6   40      011.3
01   41      028.1   42      015.4   43      081.4   44      051.7   45      074.0
01   46      059.5   47      060.7   48      061.0   49      047.1   50      090.7
01   51      065.5   52      080.0
02   01      100.0   02      031.5   03      000.0   04      085.5   05      100.0
02   06      035.8   07      082.1   08      018.9   09      000.0   10      000.0
02   11      000.0   12      000.0   13      009.5   14      017.4   15      002.8
02   16      000.0   17      001.0   18      001.5   19      002.6   20      000.0
02   21      002.1   22      001.3   23      001.7   24      001.8   25      001.8
02   26      000.0   27      000.2   28      000.4   29      000.2   30      000.0
02   31      000.4   32      000.1   33      000.2   34      000.4   35      026.3
02   36      029.2   37      050.0   38      000.0   39      073.7   40      070.8
02   41      050.0   42      100.0   43      073.7   44      060.3   45      090.6
02   46      100.0   47      091.0   48      087.3   49      088.2   50      041.2
02   51      065.5   52      100.0
03   01      010.3   02      006.4   03      000.4   04      000.0   05      000.0
03   06      010.1   07      002.7   08      014.0   09      048.6   10      052.5
03   11      053.1   12      050.0   13      019.8   14      025.4   15      023.3
03   16      032.4   17      090.0   18      098.5   19      075.0   20      091.3
03   21      024.4   22      011.3   23      020.7   24      022.4   25      022.6
03   26      061.6   27      031.4   28      054.4   29      024.4   30      049.3
03   31      006.4   32      001.9   33      007.8   34      005.4   35      077.7
03   36      082.5   37      076.1   38      085.0   39      022.3   40      017.5
03   41      023.9   42      015.0   43      077.7   44      065.5   45      086.6
03   46      084.9   47      073.8   48      079.3   49      076.5   50      093.2
03   51      056.9   52      080.0
04   01      029.8   02      012.5   03      005.1   04      073.4   05      094.5
04   06      089.2   07      097.5   08      049.7   09      100.0   10      176.5
04   11      000.0   12      088.0   13      092.5   14      096.8   15      084.1
04   16      074.5   17      020.1   18      002.9   19      001.3   20      018.6
04   21      032.1   22      036.4   23      020.7   24      018.0   25      038.1
04   26      050.0   27      029.7   28      018.4   29      000.0   30      031.1
04   31      047.1   32      044.2   33      037.0   34      022.9   35      031.0
04   36      006.3   37      000.0   38      045.6   39      069.0   40      093.7
04   41      100.0   42      054.4   43      069.0   44      007.5   45      024.4
04   46      034.6   47      022.8   48      021.3   49      094.1   50      088.2
04   51      100.0   52      050.0
05   01      036.0   02      022.9   03      010.8   04      065.9   05      056.7
05   06      040.6   07      066.5   08      061.7   09      092.1   10      085.9
05   11      100.0   12      096.0   13      078.7   14      086.4   15      069.8
05   16      061.1   17      056.4   18      000.0   19      034.9   20      078.4
05   21      086.0   22      100.0   23      073.3   24      043.0   25      083.9
05   26      049.1   27      070.7   28      000.0   29      040.2   30      155.6
05   31      100.0   32      100.0   33      100.0   34      036.8   35      033.5
05   36      000.0   37      029.2   38      072.3   39      066.5   40      100.0
05   41      070.8   42      027.7   43      066.5   44      000.0   45      000.0
05   46      014.6   47      000.0   48      002.7   49      055.9   50      093.8
05   51      025.9   52      060.0
06   01      059.6   02      068.2   03      066.0   04      096.5   05      062.6
06   06      037.1   07      080.1   08      098.1   09      091.9   10      085.9
06   11      089.6   12      100.0   13      086.4   14      068.3   15      075.9
```

06	16	093.6	17	023.0	18	000.0	19	017.1	20	006.5
06	21	045.8	22	037.1	23	027.2	24	038.6	25	050.0
06	26	068.8	27	028.7	28	000.0	29	015.8	30	014.0
06	31	060.8	32	025.2	33	041.8	34	077.3	35	025.2
06	36	000.0	37	028.0	38	010.1	39	074.8	40	100.0
06	41	072.0	42	089.9	43	074.8	44	028.2	45	027.6
06	46	033.5	47	022.5	48	028.0	49	052.9	50	079.5
06	51	032.8	52	060.0						
07	01	043.4	02	020.1	03	012.2	04	056.1	05	053.8
07	06	047.9	07	058.3	08	019.0	09	036.5	10	037.7
07	11	035.9	12	038.5	13	000.0	14	009.1	15	002.3
07	16	021.7	17	087.1	18	097.1	19	100.0	20	050.2
07	21	012.5	22	000.7	23	006.9	24	012.1	25	020.2
07	26	100.0	27	017.1	28	027.7	29	014.9	30	016.0
07	31	001.3	32	000.0	33	000.9	34	001.3	35	090.3
07	36	099.1	37	094.2	38	088.3	39	009.7	40	000.9
07	41	005.8	42	011.7	43	090.3	44	060.3	45	086.6
07	46	088.6	47	076.9	48	080.0	49	035.3	50	076.4
07	51	015.5	52	060.0						
08	01	058.7	02	062.9	03	052.7	04	018.2	05	047.1
08	06	040.1	07	035.3	08	074.1	09	082.6	10	000.0
08	11	077.6	12	090.8	13	084.5	14	082.6	15	078.4
08	16	078.7	17	010.5	18	000.0	19	002.6	20	002.2
08	21	056.8	22	034.4	23	044.0	24	044.9	25	063.1
08	26	040.2	27	010.6	28	000.0	29	001.8	30	003.8
08	31	073.1	32	031.9	33	070.9	34	063.5	35	009.4
08	36	000.0	37	002.6	38	003.6	39	090.6	40	100.0
08	41	097.4	42	096.4	43	090.6	44	015.5	45	026.0
08	46	029.7	47	023.4	48	022.7	49	079.4	50	098.8
08	51	065.5	52	060.0						
09	01	045.9	02	020.1	03	007.7	04	069.9	05	082.1
09	06	100.0	07	100.0	08	017.2	09	000.0	10	000.0
09	11	000.0	12	000.0	13	019.4	14	019.6	15	019.5
09	16	041.6	17	000.0	18	000.0	19	000.0	20	000.0
09	21	100.0	22	049.0	23	100.0	24	073.2	25	100.0
09	26	000.0	27	000.0	28	000.0	29	000.0	30	000.0
09	31	025.9	32	006.1	33	032.5	34	028.9	35	000.0
09	36	000.0	37	000.0	38	000.0	39	100.0	40	100.0
09	41	100.0	42	100.0	43	100.0	44	100.0	45	100.0
09	46	089.2	47	100.0	48	100.0	49	047.1	50	078.9
09	51	048.3	52	100.0						
10	01	047.3	02	085.2	03	100.0	04	069.0	05	083.3
10	06	089.2	07	086.3	08	100.0	09	099.2	10	100.7
10	11	000.0	12	000.0	13	100.0	14	084.6	15	100.0
10	16	100.0	17	012.7	18	000.0	19	000.0	20	000.0
10	21	042.1	22	022.5	23	025.0	24	043.8	25	042.9
10	26	058.0	27	018.4	28	000.0	29	000.0	30	000.0
10	31	069.2	32	021.7	33	058.2	34	100.0	35	015.9
10	36	000.0	37	000.0	38	000.0	39	084.1	40	100.0
10	41	100.0	42	100.0	43	084.1	44	003.4	45	002.4
10	46	000.0	47	002.8	48	000.0	49	088.2	50	086.3
10	51	065.5	52	090.0						
11	01	067.2	02	035.2	03	017.9	04	078.6	05	077.6
11	06	064.5	07	090.4	08	039.3	09	045.4	10	051.9
11	11	041.1	12	046.3	13	000.2	14	000.0	15	000.0
11	16	024.7	17	050.2	18	029.4	19	054.6	20	051.9
11	21	015.3	22	003.3	23	017.2	24	020.2	25	001.8
11	26	030.4	27	015.2	28	015.9	29	010.6	30	024.0
11	31	001.6	32	000.1	33	002.0	34	002.8	35	087.0
11	36	096.7	37	084.5	38	084.0	39	013.0	40	003.3
11	41	015.5	42	016.0	43	087.0	44	062.6	45	074.8
11	46	062.2	47	072.4	48	068.7	49	100.0	50	091.3
11	51	031.0	52	080.0						
12	01	050.1	02	038.5	03	026.3	04	060.7	05	027.3
12	06	004.0	07	035.5	08	029.2	09	046.3	10	043.4
12	11	046.9	12	049.0	13	023.1	14	045.2	15	025.6
12	16	025.0	17	025.4	18	008.2	19	010.2	20	016.8
12	21	012.3	22	004.0	23	009.5	24	000.7	25	031.5
12	26	062.5	27	008.0	28	003.1	29	002.6	30	008.7
12	31	003.7	32	001.4	33	003.9	34	000.1	35	061.0
12	36	025.9	37	040.3	38	098.1	39	039.0	40	074.1
12	41	059.7	42	001.9	43	061.0	44	023.0	45	048.8
12	46	061.1	47	041.4	48	044.0	49	000.0	51	090.7
12	51	006.9	52	090.0						
13	01	000.0	02	000.0	03	009.8	04	002.6	05	010.8

13	06	000.0	07	000.0	08	006.9	09	036.5	10	060.0
13	11	052.1	12	000.0	13	031.3	14	039.4	15	030.3
13	16	041.4	17	012.1	18	001.5	19	000.0	20	003.0
13	21	064.2	22	046.4	23	054.7	24	058.1	25	045.8
13	26	048.2	27	005.7	28	001.1	29	000.0	30	000.0
13	31	025.0	32	013.7	33	026.8	34	022.8	35	014.0
13	36	001.2	37	000.0	38	000.0	39	086.0	40	098.8
13	41	100.0	42	100.0	43	086.0	44	017.2	45	014.2
13	46	034.1	47	015.9	48	020.7	49	070.6	50	086.3
13	51	056.9	52	060.0						
14	01	078.2	02	100.0	03	028.5	04	100.0	05	051.3
14	06	018.3	07	069.1	08	096.4	09	093.3	10	137.6
14	11	098.1	12	080.0	13	086.9	14	100.0	15	072.1
14	16	061.5	17	077.9	18	000.0	19	057.9	20	100.0
14	21	034.6	22	045.0	23	019.4	24	016.5	25	044.6
14	26	071.4	27	100.0	28	000.0	29	064.3	30	138.0
14	31	046.4	32	057.7	33	027.7	34	014.3	35	060.6
14	36	000.0	37	070.4	38	085.6	39	039.4	40	100.0
14	41	029.6	42	014.4	43	060.6	44	002.3	45	041.7
14	46	055.0	47	026.2	48	030.0	49	020.6	50	091.9
14	51	019.0	52	070.0						
15	01	030.3	02	014.4	03	007.3	04	054.8	05	015.0
15	06	011.2	07	032.1	08	000.0	09	028.3	10	032.0
15	11	026.8	12	027.4	13	004.2	14	017.8	15	005.5
15	16	023.7	17	026.2	18	020.6	19	019.7	20	006.5
15	21	080.5	22	018.5	23	056.5	24	100.0	25	066.1
15	26	067.0	27	003.1	28	004.2	29	001.6	30	001.0
15	31	010.6	32	002.1	33	009.3	34	012.8	35	017.2
15	36	024.8	37	015.3	38	004.8	39	082.8	40	075.2
15	41	084.7	42	095.2	43	082.8	44	048.3	45	074.8
15	46	087.6	47	061.4	48	070.0	49	011.8	50	099.4
15	51	000.0	52	040.0						
16	01	029.8	02	012.5	03	005.1	04	073.4	05	094.5
16	06	089.2	07	097.5	08	049.7	09	100.0	10	176.5
16	11	000.0	12	088.0	13	092.5	14	096.8	15	084.1
16	16	074.5	17	020.1	18	002.9	19	001.3	20	018.6
16	21	032.1	22	036.4	23	020.7	24	018.0	25	038.1
16	26	050.0	27	029.7	28	018.4	29	000.0	30	031.1
16	31	047.1	32	044.2	33	037.0	34	022.9	35	031.0
16	36	006.3	37	000.0	38	045.6	39	069.0	40	093.7
16	41	100.0	42	054.4	43	069.0	44	007.5	45	024.4
16	46	034.6	47	022.8	48	021.3	49	064.7	50	076.4
16	51	046.6	52	050.0						
17	01	059.6	02	068.2	03	066.0	04	096.5	05	062.6
17	06	037.1	07	080.1	08	098.1	09	091.9	10	085.9
17	11	089.6	12	100.0	13	086.4	14	068.3	15	075.9
17	16	093.6	17	023.0	18	000.0	19	017.1	20	006.5
17	21	045.8	22	037.1	23	027.2	24	038.6	25	050.0
17	26	068.8	27	028.7	28	000.0	29	015.8	30	014.0
17	31	060.8	32	025.2	33	041.8	34	077.3	35	025.2
17	36	000.0	37	028.0	38	010.1	39	074.8	40	100.0
17	41	072.0	42	089.9	43	074.8	44	028.2	45	027.6
17	46	033.5	47	022.5	48	028.0	49	023.5	50	064.0
17	51	053.4	52	060.0						
18	01	058.7	02	062.9	03	052.7	04	018.2	05	047.1
18	06	040.1	07	035.3	08	074.1	09	082.6	10	000.0
18	11	077.6	12	090.8	13	084.5	14	082.6	15	078.4
18	16	078.7	17	010.5	18	000.0	19	002.6	20	002.2
18	21	056.8	22	034.4	23	044.0	24	044.9	25	063.1
18	26	040.2	27	010.6	28	000.0	29	001.8	30	003.8
18	31	073.1	32	031.9	33	070.9	34	063.5	35	009.4
18	36	000.0	37	002.6	38	003.6	39	090.6	40	100.0
18	41	097.4	42	096.4	43	090.6	44	015.5	45	026.0
18	46	029.7	47	023.4	48	022.7	49	023.5	50	030.4
18	51	056.9	52	060.0						
19	01	050.1	02	038.5	03	026.3	04	060.7	05	027.3
19	06	004.0	07	035.5	08	029.2	09	046.3	10	043.4
19	11	046.9	12	049.0	13	023.1	14	045.2	15	025.6
19	16	025.0	17	025.4	18	008.2	19	010.2	20	016.8
19	21	012.3	22	004.0	23	009.5	24	000.7	25	031.5
19	26	062.5	27	008.0	28	003.1	29	002.6	30	008.7
19	31	003.7	32	001.4	33	003.9	34	000.1	35	061.0
19	36	025.9	37	040.3	38	098.1	39	039.0	40	074.1
19	41	059.7	42	001.9	43	061.0	44	023.0	45	048.8
19	46	061.1	47	041.4	48	044.0	49	008.8	50	000.0

```
19   51      058.6   52      090.0
20   01      028.9   02      005.0   03      009.3   04      044.6   05      031.4
20   06      047.0   07      047.2   08      005.6   09      049.2   10      045.5
20   11      053.1   12      052.4   13      027.7   14      030.8   15      030.4
20   16      035.6   17      000.2   18      000.0   19      000.0   20      000.0
20   21      000.0   22      000.0   23      000.0   24      000.0   25      000.0
20   26      000.9   27      000.1   28      000.0   29      000.0   30      000.0
20   31      000.0   32      000.0   33      000.0   34      000.0   35      100.0
20   36      000.0   37      000.0   38      000.0   39      000.0   40      000.0
20   41      000.0   42      000.0   43      100.0   44      025.5   45      056.5
20   46      027.0   47      050.9   48      038.0   49      011.8   50      031.4
20   51      046.6   52      100.0
 0
LL      LW      LC      CL-b    CL-c    CL-t    CL-ave  CW      PD-CC-avPD-CC-b
PD-CC-c PD-CC-t PD-CV-avPD-CV-b PD-CV-c PD-CV-t PF-CC-avPF-CC-b PF-CC-c PF-CC-t
PF-CV-avPF-CV-b PF-CV-c PF-CV-t PF-CV-e PF-CC-e PA-CC-avPA-CC-b PA-CC-c PA-CC-t
PA-CV-avPA-CV-b PA-CV-c PA-CV-t %PA-CC-a%PA-CC-b%PA-CC-c%PA-CC-t%PA-CV-a%PA-CV-b
%PA-CV-c%PA-CV-t%PA-L   FF-b    FF-c    FF-t    FF-e    FF-ave  density dry wt
% water Habitat
ang     cus     fal     fus     gir     imb     lin     mag     maj     pap
pul     rip-em  rub     squ     wul     fus-W   imb-W   mag-W   rip-em-Wrip-sb-W
```

Canoco Input Table 2: Absorbency data. Left hand column is species number (listed in sequential order at the end of the table). Other columns are scores for absorbency features, listed in the order in which they appear at the end of the table.

```
(i2,7(f8.1))
 7
01   015.9   004.5   003.5   033.9   017.7   042.7   100.0
02   012.8   005.0   004.4   035.9   017.6   049.5   100.0
03   016.1   003.6   002.6   040.6   019.8   051.8   100.0
04   014.6   002.7   001.8   040.9   018.0   052.7   100.0
05   013.3   004.1   001.9   032.6   022.1   057.6   100.0
06   012.4   005.2   002.3   037.1   023.8   062.1   091.8
07   013.3   004.7   003.2   028.1   017.3   047.8   093.7
08   016.9   003.1   001.7   027.8   016.3   042.9   100.0
09   013.8   005.4   004.6   027.9   014.4   038.2   100.0
10   015.7   003.2   001.9   034.3   017.9   051.9   100.0
11   013.6   005.3   004.3   034.1   021.4   045.1   100.0
12   015.4   003.9   003.5   035.1   020.6   063.1   100.0
13   015.6   004.0   002.9   031.1   014.9   038.3   100.0
14   011.5   006.6   002.9   027.2   015.8   059.1   074.8
15   009.2   004.0   002.8   021.5   014.1   030.1   068.9
16   013.0   002.9   001.7   040.9   018.0   052.7   100.0
17   011.2   004.1   002.2   025.5   018.4   044.5   045.4
18   017.8   003.4   002.0   027.8   016.3   042.9   100.0
19   016.1   005.3   004.6   036.0   019.4   058.7   100.0
20   016.6   004.9   004.1   038.7   021.4   069.1   100.0
 0
gats    dp 30   dp 120  rc300   rc1200  rc max  impact
ang     cus     fal     fus     gir     imb     lin     mag     maj     pap
pul     rip-em  rub     squ     wul     fus-W   imb-W   mag-W   rip-em-Wrip-sb-W
```

CANOCO Output Table 1: Eigenvalues for DCCA analysis of CANOCO input data (tables 1 and 2).

All species, all absorbency treatments

```
Axes                                    1     2     3     4  Total inertia

 Eigenvalues                      :  .132  .044  .014  .004           .531
 Lengths of gradient              : 1.114 1.060  .590  .535
 Species-environment correlations :  .876  .704  .859  .688
 Cumulative percentage variance
   of species data                :  24.9  33.1  35.8  36.5
   of species-environment relation:  50.4  69.1    .0    .0
 Sum of all unconstrained eigenvalues                                 .531
 Sum of all canonical     eigenvalues                                 .263
```

All species, no retention capacity

```
Axes                                    1     2     3     4  Total inertia

 Eigenvalues                      :  .130  .021  .008  .004           .531
 Lengths of gradient              : 1.128  .575  .518  .699
 Species-environment correlations :  .875  .504  .548  .691
 Cumulative percentage variance
   of species data                :  24.5  28.5  30.0  30.8
   of species-environment relation:  69.6  81.2    .0    .0
 Sum of all unconstrained eigenvalues                                 .531
 Sum of all canonical     eigenvalues                                 .188
```

Species in Section Sphagnum

```
Axes                                    1     2     3     4  Total inertia

 Eigenvalues                      :  .043  .004  .000  .000           .090
 Lengths of gradient              :  .569  .269  .000  .000
 Species-environment correlations : 1.000 1.000  .000  .000
 Cumulative percentage variance
   of species data                :  47.8  51.8    .0    .0
   of species-environment relation:  47.5  54.2    .0    .0
 Sum of all unconstrained eigenvalues                                 .090
 Sum of all canonical     eigenvalues                                 .090
```

Species in Section Acutifolia

```
Axes                                    1     2     3     4  Total inertia

 Eigenvalues                      :  .116  .002  .000  .000           .216
 Lengths of gradient              :  .919  .223  .223  .223
 Species-environment correlations : 1.000 1.000 1.000  .000
 Cumulative percentage variance
   of species data                :  54.1  55.0  55.2  55.4
   of species-environment relation:  53.3  54.2    .0    .0
 Sum of all unconstrained eigenvalues                                 .216
 Sum of all canonical     eigenvalues                                 .216
```

Species in section Cuspidata

```
Axes                                    1     2     3     4  Total inertia

 Eigenvalues                      :  .141  .028  .005  .001           .447
 Lengths of gradient              : 1.345  .712  .745  .670
 Species-environment correlations :  .905  .781  .752  .859
 Cumulative percentage variance
   of species data                :  31.5  37.8  38.9  39.1
   of species-environment relation:  55.5  70.3    .0    .0
 Sum of all unconstrained eigenvalues                                 .447
 Sum of all canonical     eigenvalues                                 .256
```

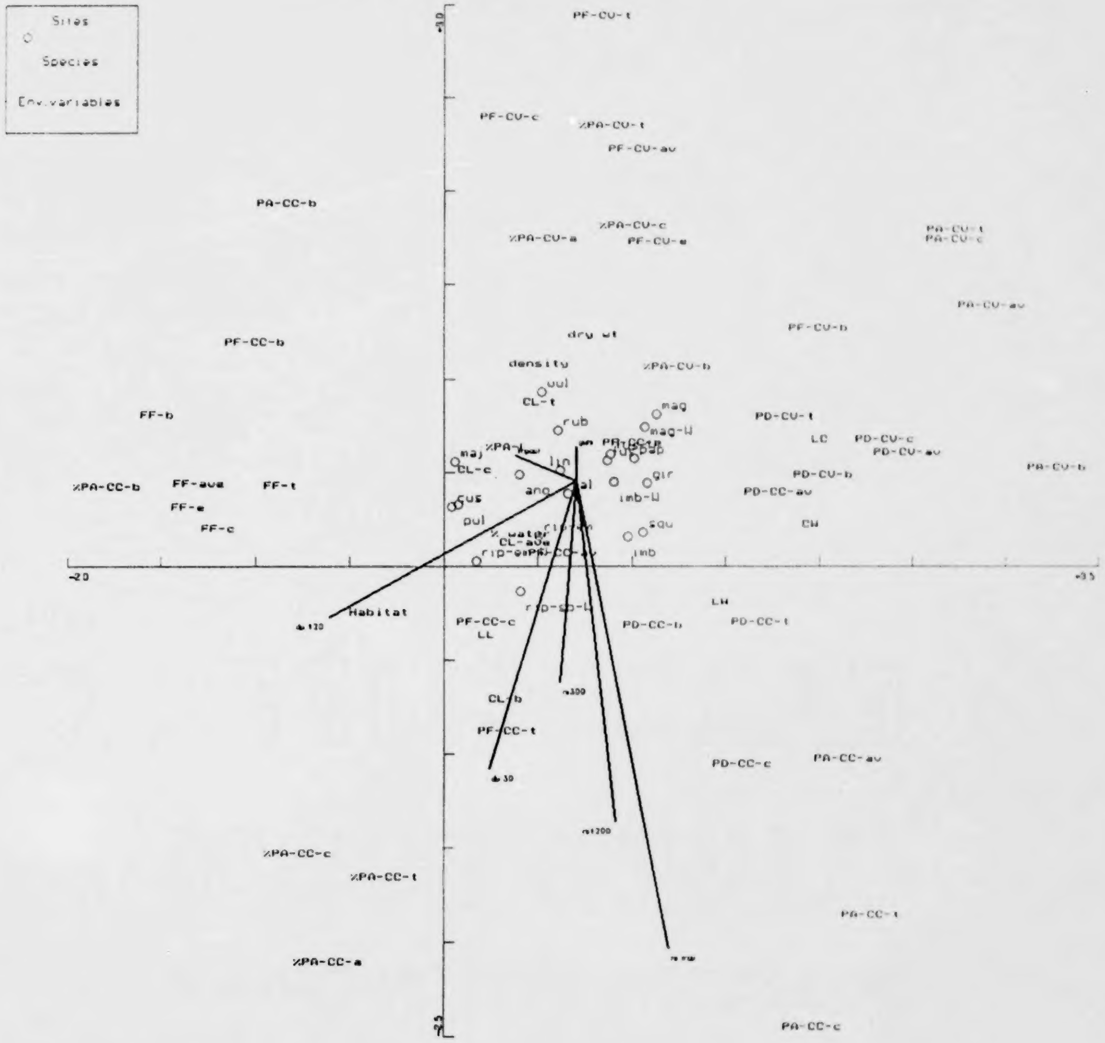
CANOCO Program Information

Program CANOCO Version 3.12 April 1991 - written by Cajo J.F. Ter Braak
Copyright (c) 1988-1991 Agricultural Mathematics Group DLO
Box 100, 6700 AC Wageningen, the Netherlands.
CANOCO performs (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis.
CANOCO is an extension of Cornell Ecology program DECORANA (Hill,1979)

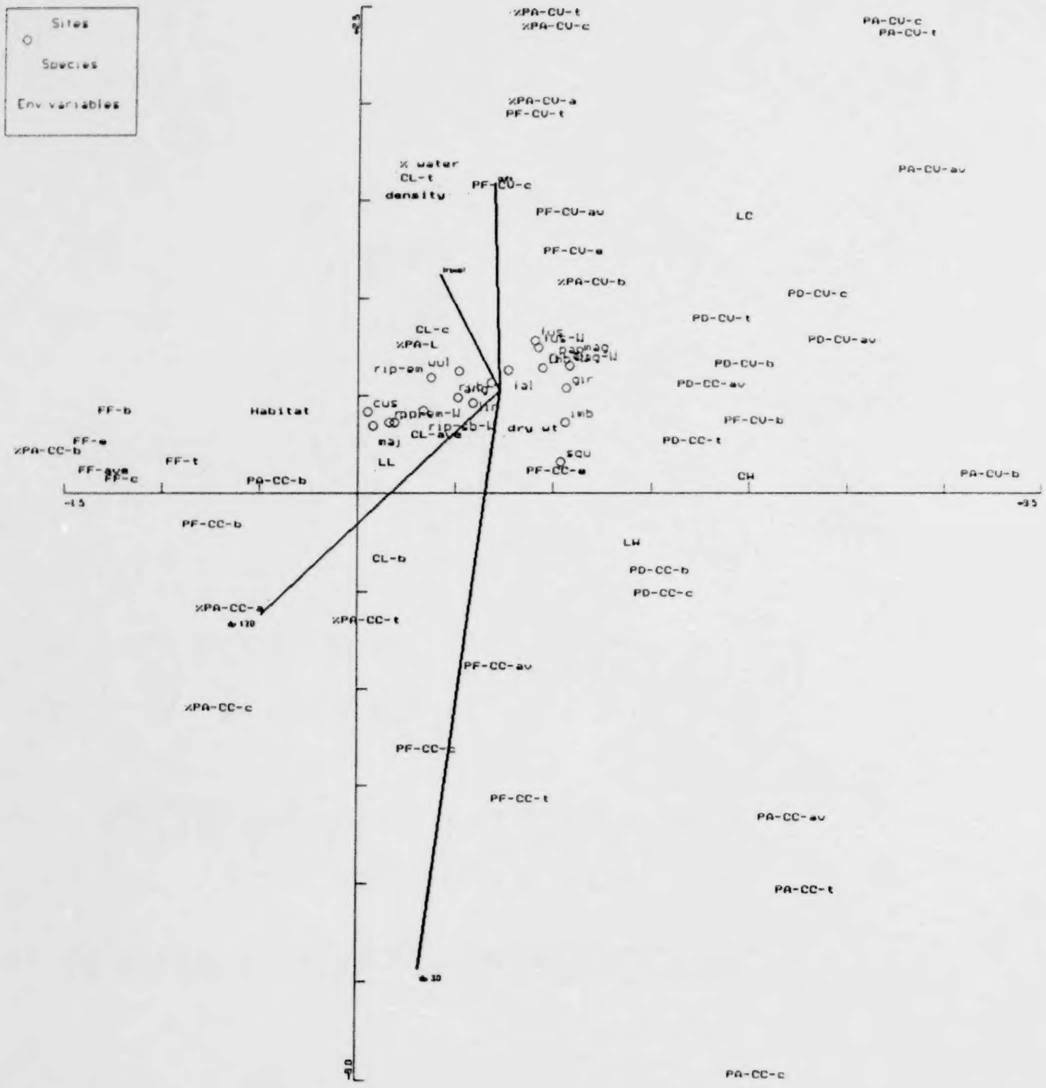
For explanation of the input/output see the manual or
Ter Braak, C.J.F. (1987) Ordination. Chapter 5 in:
Data Analysis in Community and Landscape Ecology
(Jongman, R.H.G., Ter Braak, C.J.F. and Van Tongeren, O.F.R., Eds), Pudoc, Wageningen.

All Species

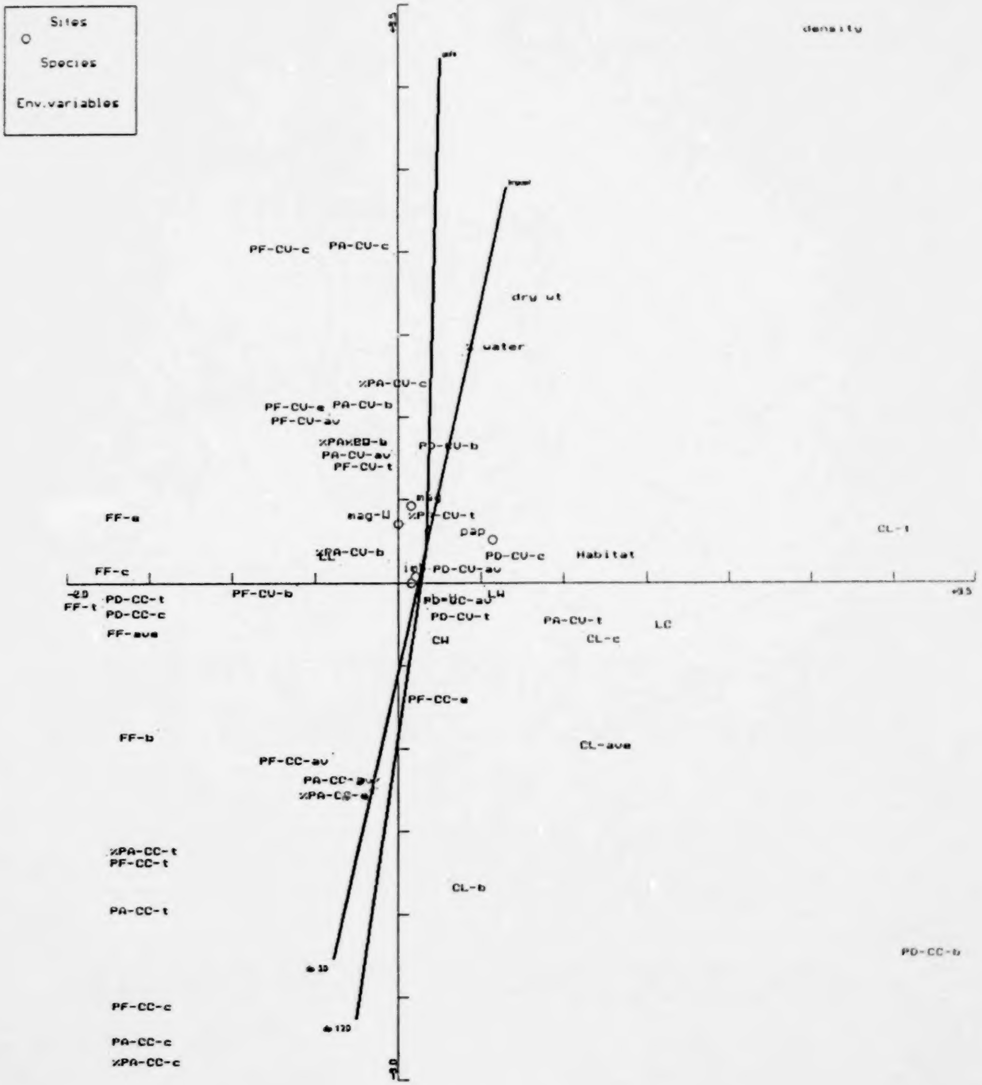
GATS, Drying Power, Impact and Retention Capacity



All Species
(no retention Capacity)



Sphagnum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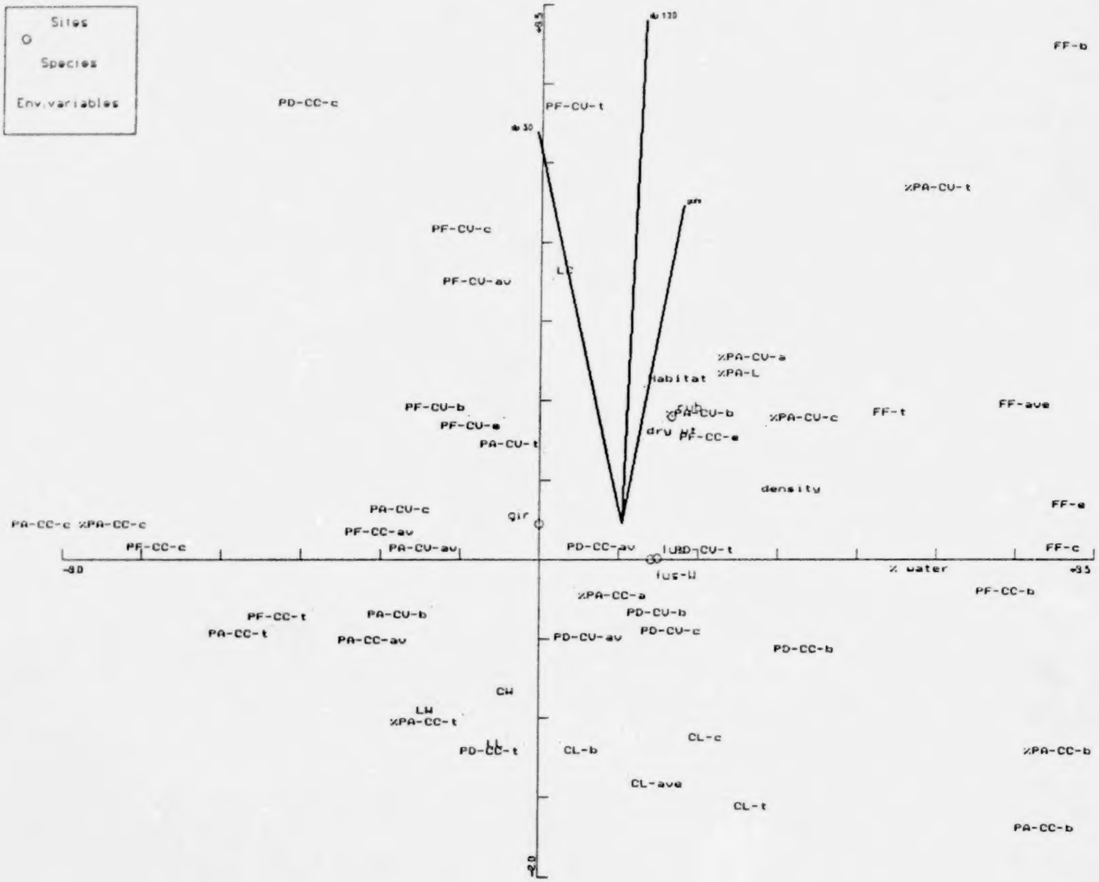
PA-CU-c
dry wt
% water
%PA-CU-c
PF-CU-e
PA-CU-b
PF-CU-av
%PA×BD-b
PD-CU-b
PA-CU-av
PF-CU-t
mag
mag-W
%PF-CU-t
FF-e
CL-t
pap
%PA-CU-b
LL
PD-CU-c
Habitat
FF-c
PD-CU-av
-2.0
PF-CU-b
+3.5
FF-t
PD-CC-t
PD-CC-c
PD-UC-av
LW
PD-CU-t
PA-CU-t
LC
FF-ave
CW
CL-c
PF-CC-e
FF-b
CL-ave
PF-CC-av
PA-CC-av
%PA-CC-e
%PA-CC-t
PF-CC-t
CL-b
PA-CC-t
PD-CC-b
30
120
PF-CC-c
PA-CC-c
%PA-CC-c
-3.0

Acutifolia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LC
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%PA-CU-a
%PA-L
Habitat
sub
%PA-CU-b
%PA-CU-c
FF-t
FF-ave
PF-CU-b
PF-CU-e
dry wt
PF-CC-e
PA-CU-t
density
FF-e
PA-CU-c
gir
PA-CC-c %PA-CC-c
PF-CC-av
PF-CC-c
PA-CU-av
PD-CC-av
PD-CU-t
FF-c
fus-W
% water
%PA-CC-a
PF-CC-b
PF-CC-t
PA-CU-b
PD-CU-b
PA-CC-t
PA-CC-av
PD-CU-av
PD-CU-c
PD-CC-b
CW
LW
%PA-CC-t
LL
PD-CC-t
CL-b
CL-c
%PA-CC-b
CL-ave
CL-t
PA-CC-b

Appendix 3: GATS and Drying Power in 1989 Study

Table 1: GATS (ml/g) and Drying Power (ml/g) in 1989 study. For drying power, the initial moisture load was 5 ml (compared to 10 ml in current study), and the liquid used had a viscosity 6 times greater that of distilled water, rather than 25 times the viscosity of distilled water in the current study..

Species	**GATS**	**Drying Power 30 min**	**Drying Power 120 min**
S. compactum	23.0	9.3	7.4
S. cuspidatum	21.5	5.1	3.2
S. fuscum	24.5	5.8	3.1
S. magellanicum	18.0	5.3	2.5
S. papillosum	20.0	5.8	2.7
S. recurvum	23.5	9.5	8.2
S. rubellum	22.0	6.9	3.5
S. subsecundum	26.0	10.2	8.8
Peat from Ste. Marguerite	16.5	2.7	1.7

Appendix 4: Results For Normality (Lilliefors statistic) and Homogeneity of Variance (Levene statistic) Tests

if K-S < 0.05, data is not normal ,if Levene < 0.05 variances are not equal
(id = insufficient data)

Leaf Length		**K-S(Lilliefors)**			**Levene**
Species	1	2	3	4	
S. angustifolium	.1825	>.2000	.1176		.0000
S. cuspidatum	>.2000	.1471			.3037
S. fallax	id				
S. fuscum	>.2000	>.2000	.0856		.1834
S. girgensohnii	.1535	> .2000	.0542		.0286
S. imbricatum	> .2000	.2000	> .2000		.0963
S. jensenii	> .2000	> .2000	.1447		.1088
S. lindbergii	> .2000	> .2000	> .2000		.6680
S. magellanicum	> .2000	.0083	> .2000		.3609
S. majus	> .2000	> .2000	> .2000	.1867	.1786
S. papillosum	> .2000	> .2000	> .2000		.1656
S. pulchrum	> .2000	> .2000	id		.0003
S. riparium - em	> .2000	> .2000			.0007
S. riparium - sub	id				
S. rubellum	> .2000	> .2000	.1979	.0685	.0547
S. squarrosum	> .2000	> .2000			.7742
S. wulfianum	> .2000	> .2000	.1642		.0856

Leaf Width		**K-S(Lilliefors)**			**Levene**
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum	id	id	id		id
S. fallax	id				
S. fuscum	id	> .2000	> .2000		.3687
S. girgensohnii	> .2000	> .2000	id		.4898
S. imbricatum					
S. jensenii	> .2000	> .2000	id		.3332
S. lindbergii	> .2000	> .2000	id		.0929
S. magellanicum	id	.1641	> .2000		.5948
S. majus	> .2000	> .2000	id	id	.7693
S. papillosum	id	> .2000	> .2000		.5061
S. pulchrum	> .2000	> .2000	id		.5273
S. riparium - em	id	id			
S. riparium - sub	id				
S. rubellum	id	id	.1913	id	
S. squarrosum	id	> .2000			
S. wulfianum	.1931	.1295	id		.1543

Leaf Curvature	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	> .2000	.1839	> .2000		.5541
S. cuspidatum	.0129	> .2000	id		.1772
S. fallax	id				
S. fuscum	.1523	> .2000	id		.7706
S. girgensohnii	id	> .2000	.0837		.1353
S. imbricatum	.1175	> .2000	> .2000		.2833
S. jensenii	id	id	.1763		
S. lindbergii	.0135	id	id		.2707
S. magellanicum	> .2000	id	id		id
S. majus	> .2000	> .2000	> .2000	> .2000	.4732
S. papillosum	id	id	id		id
S. pulchrum	id	id	id		.9072
S. riparium - em	> .2000	.1991			.7395
S. riparium - sub	id				
S. rubellum	.0579	.1503	> .2000	.0539	.0123
S. squarrosum	id	id			id
S. wulfianum	> .2000	.0222	.0024		.0812

Hyaline cell length - basal	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	> .2000	> .2000	> .2000		.0987
S. cuspidatum	> .2000	> .2000	> .2000		.0712
S. fallax	id				
S. fuscum	> .2000	> .2000	> .2000		.8118
S. girgensohnii	> .2000	> .2000	> .2000		.7411
S. imbricatum	> .2000	> .2000	> .2000		.2200
S. jensenii	> .2000	.1457	> .2000		.5489
S. lindbergii	> .2000	> .2000	> .2000		.4416
S. magellanicum	> .2000	> .2000	> .2000		.1518
S. majus	> .2000	> .2000	> .2000	> .2000	.8958
S. papillosum	> .2000	> .2000	> .2000		.0014
S. pulchrum	> .2000	> .2000	> .2000		.5373
S. riparium - em	> .2000	.1442			.7398
S. riparium - sub	id				
S. rubellum	> .2000	> .2000	> .2000	> .2000	.9086
S. squarrosum	> .2000	> .2000			.0576
S. wulfianum	> .2000	> .2000	> .2000		.5276

Hyaline cell length - centre		K-S(Lilliefors)			Levene
Species	1	2	3	4	
S. angustifolium	> .2000	> .2000	> .2000		.1042
S. cuspidatum	> .2000	> .2000			.0551
S. fallax	id				
S. fuscum	> .2000	> .2000	> .2000		.9335
S. girgensohnii	> .2000	> .2000	> .2000		.1685
S. imbricatum	> .2000	> .2000	.1569		.2876
S. jensenii	> .2000	> .2000	> .2000		.5254
S. lindbergii	> .2000	.0270	> .2000		.0350
S. magellanicum	> .2000	.1715	> .2000		.0724
S. majus	> .2000	> .2000	> .2000	> .2000	.0127
S. papillosum	> .2000	> .2000	> .2000		.3852
S. pulchrum	.0048	> .2000	.1004		.0771
S. riparium - em	> .2000	> .2000			.1427
S. riparium - sub	id				
S. rubellum	> .2000	> .2000	> .2000	> .2000	.2580
S. squarrosum	> .2000	> .2000			.9014
S. wulfianum	> .2000	> .2000	.1881		.1657

Hyaline cell length - tip		K-S(Lilliefors)			Levene
Species	1	2	3	4	
S. angustifolium	> .2000	.0382	.1054		.9590
S. cuspidatum	> .2000	> .2000			.0834
S. fallax	id				
S. fuscum	> .2000	> .2000	> .2000		.8260
S. girgensohnii	> .2000	> .2000	> .2000		.7864
S. imbricatum	> .2000	> .2000	> .2000		.2795
S. jensenii	> .2000	> .2000	> .2000		.2956
S. lindbergii	> .2000	.1339	> .2000		.4171
S. magellanicum	.0274	> .2000	> .2000		.0165
S. majus	> .2000	> .2000	> .2000	> .2000	.1691
S. papillosum	> .2000	> .2000	> .2000		.0464
S. pulchrum	> .2000	> .2000	> .2000		.3039
S. riparium - em	> .2000	> .2000			.6439
S. riparium - sub	id				
S. rubellum	> .2000	.0040	> .2000	> .2000	.0939
S. squarrosum	> .2000	> .2000			.0576
S. wulfianum	> .2000	.1105	> .2000		.1267

Hyaline cell width Species	K-S(Lilliefors) 1	2	3	4	Levene
S. angustifolium	> .2000	> .2000	> .2000		.1098
S. cuspidatum	.0111	> .2000			.7343
S. fallax	id				
S. fuscum	.1629	> .2000	> .2000		.5763
S. girgensohnii	> .2000	.0627	> .2000		.8893
S. imbricatum	.0251	.1436	> .2000		.3304
S. jensenii	> .2000	> .2000	> .2000		.5135
S. lindbergii	> .2000	> .2000	> .2000		.0611
S. magellanicum	> .2000	> .2000	.1370		.3252
S. majus	.1070	> .2000	> .2000	> .2000	.7214
S. papillosum	.0093	.0731	> .2000		.0008
S. pulchrum	> .2000	> .2000	> .2000		.2106
S. riparium - em	.1690	> .2000			.1313
S. riparium - sub	id				
S. rubellum	> .2000	> .2000	.1546	> .2000	.2000
S. squarrosum	> .2000	> .2000			.3594
S. wulfianum	> .2000	.0298	> .2000		.0425

Fibril Frequency Species	K-S(Lilliefors) base	centre	tip	edge
S. angustifolium	> .2000	.0410	> .2000	> .2000
S. cuspidatum	> .2000	> .2000	> .2000	> .2000
S. fallax	> .2000	> .2000	> .2000	> .2000
S. fuscum	.0456	> .2000	> .2000	> .2000
S. girgensohnii	> .2000	> .2000	.0859	.0000
S. imbricatum	> .2000	> .2000	> .2000	> .2000
S. lindbergii	> .2000	> .2000	> .2000	> .2000
S. magellanicum	> .2000	> .2000	> .2000	> .2000
S. majus	.0281	> .2000	> .2000	> .2000
S. papillosum	> .2000	.1331	.1887	.0015
S. pulchrum	.0987	.1207	> .2000	> .2000
S. riparium - em	> .2000	> .2000	> .2000	.0236
S. riparium - sub	> .2000	.0299	> .2000	> .2000
S. rubellum	> .2000	> .2000	> .2000	> .2000
S. squarrosum	> .2000	.1932	> .2000	.0567
S. wulfianum	> .2000	> .2000	> .2000	> .2000
Levene	.0757	.0053	.0190	0052

Concave Pore diameter - basal	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum	id	id	id		id
S. fallax	id				
S. fuscum	id	id	id		id
S. girgensohnii	id	id	id		id
S. imbricatum	id	id	id		id
S. jensenii	id	.0219	.0507		.2380
S. lindbergii		> .2000	> .2000		.0765
S. magellanicum	id	id	id		id
S. majus	id	id	id		id
S. papillosum	> .2000	id	id		id
S. pulchrum	.0041	> .2000	> .2000		.8251
S. riparium - em	.0005	> .2000			.4784
S. riparium - sub	id				
S. rubellum	id	id	id	id	id
S. squarrosum	id	id			
S. wulfianum	id	id	id		id

Concave Pore diameter - centre	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum	id	id	id		id
S. fallax	id				
S. fuscum	id	id	id		id
S. girgensohnii	> .2000	id	id		id
S. imbricatum	id	id	id		id
S. jensenii	id	.0005	id		.0639
S. lindbergii	id	> .2000	id		.3182
S. magellanicum	id	id	id		id
S. majus	id	id	id	id	id
S. papillosum	id	id	id		id
S. pulchrum	.0261	all equal	> .2000		.8688
S. riparium - em	> .2000	> .2000			.7009
S. riparium - sub	id				
S. rubellum	id	id	id	id	id
S. squarrosum	id	> .2000			.7462
S. wulfianum	id	id	id		id

Concave Pore diameter - tip	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum	id	id	id		id
S. fallax	id				
S. fuscum	id	id	id		id
S. girgensohnii	> .2000	> .2000	> .2000		.1288
S. imbricatum	id	id	id		id
S. jensenii	id	> .2000	id		id
S. lindbergii	> .2000	> .2000	> .2000		.3965
S. magellanicum	id	id	id		id
S. majus	id	id	id	id	id
S. papillosum	id	id	id		id
S. pulchrum	> .2000	.0005	> .2000		.2802
S. riparium - em	> .2000	> .2000			.4227
S. riparium - sub	id				
S. rubellum	id	id	id	id	id
S. squarrosum	.0026	> .2000			.2939
S. wulfianum	id	id	id		id

Convex Pore diameter - basal	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	id	id	id	id	id
S. cuspidatum					
S. fallax					
S. fuscum	> .2000	> .2000	id		.2148
S. girgensohnii	.0120	> .2000	> .2000		.4426
S. imbricatum	.1819	> .2000	id		.4609
S. jensenii	> .2000	.0029	> .2000		.2959
S. lindbergii	id	> .2000	> .2000		.0765
S. magellanicum	> .2000	> .2000	> .2000		.2941
S. majus	> .2000	.1628	> .2000	id	.1540
S. papillosum	> .2000	> .2000	> .2000		.7137
S. pulchrum	id	id	.0261		id
S. riparium - em	id	id			id
S. riparium - sub					
S. rubellum	id	id	> .2000	id	id
S. squarrosum	id	> .2000			.1418
S. wulfianum	id	> .2000	id		id

Convex Pore diameter - centre		K-S(Lilliefors)			Levene
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum					
S. fallax					
S. fuscum	.1964	> .2000	id		.9645
S. girgensohnii	.0634	> .2000	> .2000		.1399
S. imbricatum	> .2000	> .2000	> .2000		.9342
S. jensenii	.0853	.0005	.0327		.0491
S. lindbergii	id	id	> .2000		.6635
S. magellanicum	> .2000	> .2000	> .2000		.2674
S. majus	id	.1135	> .2000	id	.4396
S. papillosum	> .2000	> .2000	> .2000		.7117
S. pulchrum			.0005		.2783
S. riparium - em	id	.1869			id
S. riparium - sub	id	id			id
S. rubellum	> .2000	> .2000	.1607	.1607	.6167
S. squarrosum	id	> .2000			.0232
S. wulfianum	> .2000	> .2000	> .2000		.0179

Convex Pore diameter - tip		K-S(Lilliefors)			Levene
Species	1	2	3	4	
S. angustifolium	id	id	id		id
S. cuspidatum	id	id	id		id
S. fallax	id				
S. fuscum	> .2000	> .2000	id		.4108
S. girgensohnii	> .2000	> .2000	.0120		.0008
S. imbricatum	.0752	id	> .2000		.8135
S. jensenii	.0005	all equal	.0005		.2672
S. lindbergii	id	> .2000	> .2000		.9970
S. magellanicum	> .2000	> .2000	> .2000		.3969
S. majus	> .2000	> .2000	> .2000	id	.2997
S. papillosum	.0430	> .2000	> .2000		.0004
S. pulchrum	> .2000	> .2000	.0261		.9789
S. riparium - em	id	id			id
S. riparium - sub	id				
S. rubellum	> .2000	> .2000	.1475	> .2000	.4863
S. squarrosum	id	.1607			id
S. wulfianum	> .2000	.0623	> .2000		.1440

Convex Pore diameter - all parts of leaf	K-S(Lilliefors)				Levene
Species	1	2	3	4	
S. angustifolium	> .2000	> .2000	> .2000		.0003
S. cuspidatum	id	id	id		id
S. fallax	id	id	id		id
S. fuscum	.0047	.1551	> .2000		.0732
S. girgensohnii	> .2000	> .2000	.0057		.9361
S. imbricatum	.0744	.0573	.0192		.6193
S. jensenii	.0000	.0000	.0000		.0575
S. lindbergii	> .2000	> .2000	.0639		.7310
S. magellanicum	> .2000	.0002	> .2000		.9136
S. majus	> .2000	.0206	.0607	.0342	.4451
S. papillosum	> .2000	> .2000	> .2000		.8724
S. pulchrum	.0812	.0789	.0000		.1656
S. riparium - em	id	.0039			.5633
S. riparium - sub	id	id	id		id
S. rubellum	> .2000	> .2000	.0247	> .2000	.2243
S. squarrosum	> .2000	.1880			.1123
S. wulfianum	> .2000	.0004	.0885		.5850

Concave Pore frequency	K-S(Lilliefors)			
Species	base	centre	tip	edge
S. angustifolium	> .2000	> .2000	.0540	> .2000
S. cuspidatum	.0000	.0002	.0000	none
S. fallax	> .2000	> .2000	.1236	> .2000
S. fuscum	.0000	.0000	.1213	.0005
S. girgensohnii	none	> .2000	> .2000	> .2000
S. imbricatum	none	> .2000	.1985	> .2000
S. lindbergii	.1481	> .2000	.1971	> .2000
S. magellanicum	none	.0002	> .2000	> .2000
S. majus	none	none	> .2000	none
S. papillosum	none	none	.1085	> .2000
S. pulchrum	.0001	.0977	.0083	> .2000
S. riparium - em	.0000	> .2000	> .2000	> .2000
S. riparium - sub	none	none	none	.0000
S. rubellum	.0000	none	.0234	> .2000
S. squarrosum	none	> .2000	> .2000	> .2000
S. wulfianum	.1308	.0272	> .2000	.0186
Levene Statistic	.0000	.0000	.0000	.0001

Convex Pore frequency	K-S(Lilliefors)			
Species	base	centre	tip	edge
S. angustifolium	.0000	.0540	.1331	.0238
S. cuspidatum	.0000	.0000	.0030	.0000
S. fallax	.0761	.1236	.1961	> .2000
S. fuscum	> .2000	.1213	.0286	.0437
S. girgensohnii	> .2000	> .2000	.1484	> .2000
S. imbricatum	> .2000	.1985	.0573	> .2000
S. lindbergii	.0000	.1971	.1271	.0902
S. magellanicum	> .2000	> .2000	> .2000	> .2000
S. majus	.0082	> .2000	> .2000	.0335
S. papillosum	> .2000	.1085	.0209	.0025
S. pulchrum	.0030	.0083	.1906	.0000
S. riparium - em	.0000	> .2000	.0000	.0139
S. riparium - sub	none	none	none	none
S. rubellum	> .2000	.0234	> .2000	> .2000
S. squarrosum	.0015	> .2000	> .2000	> .2000
S. wulfianum	.0963	> .2000	> .2000	> .2000
Levene Statistic	.0000	.0000	.0000	.0009

Leaf Curvature	K-S(Lilliefors)		Levene
Species	calendered	uncalendered	
S. angustifolium	> .2000	> .2000	.2289
S. cuspidatum	> .2000	> .2000	.3268
S. fallax	.0043	> .2000	.0317
S. fuscum	.1678	.1394	.1904
S. magellanicum	> .2000	> .2000	.5636
S. majus	> .2000	> .2000	.9649
S. papillosum	> .2000	.1335	.0332
S. pulchrum	.0392	> .2000	.4918
S. rubellum	> .2000	> .2000	.2289

Leaf Length	K-S(Lilliefors)		Levene
Species	calendered	uncalendered	
S. angustifolium	> .2000	.0501	.2295
S. cuspidatum	> .2000	> .2000	.0925
S. fallax	> .2000	> .2000	.0402
S. fuscum	> .2000	> .2000	.7746
S. magellanicum	> .2000	> .2000	.3020
S. majus	> .2000	> .2000	.6716
S. papillosum	> .2000	> .2000	.0033
S. pulchrum	> .2000	.0840	.5141
S. rubellum	.1746	> .2000	.0281

Leaf Width Species	K-S(Lilliefors) calendered	K-S(Lilliefors) uncalendered	Levene
S. angustifolium	.0038	.0357	.1187
S. cuspidatum	.0721	.1160	.0642
S. fallax	.1162	.0021	.5683
S. fuscum	> .2000	> .2000	.0692
S. magellanicum	> .2000	.0747	.0558
S. majus	> .2000	> .2000	.1800
S. papillosum	> .2000	> .2000	.0131
S. pulchrum	> .2000	> .2000	.4656
S. rubellum	> .2000	> .2000	.8935